12

TECHNICAL REPORT HL-82-9

EFFECTS OF STORAGE REALLOCATION ON THERMAL CHARACTERISTICS OF COWANESQUE LAKE, PENNSYLVANIA

Numerical Model Investigation

by

Jeffery P. Holland

Hydraulics Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

April 1982

Final Report

Prepared for U. S. Army Engineer District, Baltimore
Baltimore, Md. 21203

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report HL-82-9	2. GOVT ACCESSION NO. AD-A118007	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) EFFECTS OF STORAGE REALLOCATION ON THERMAL CHARACTERISTICS OF COWANESQUE LAKE, PENNSYLVANIA; Numerical Model Investigation		5. TYPE OF REPORT & PERIOD COVERED Final report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Jeffery P. Holland		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Hydraulics Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Engineer District, Baltimore P. O. Box 1715 Baltimore, Md. 21203		12. REPORT DATE April 1982
		13. NUMBER OF PAGES 116
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Cowanesque Lake (Pa.)	Water-supply
Numerical analysis	Water use
Reservoirs	Optimization

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Growing consumptive use of water in the Susquehanna River Basin has prompted the U. S. Army Engineer District, Baltimore, to examine the feasibility of reallocating a portion of flood-control storage of Cowanesque Lake to water supply storage. This reallocation would result in increases to normal pool elevation which may alter the thermal structure of the lake and render the present selective withdrawal system inadequate for release temperature maintenance. A one-dimensional numerical model was used to evaluate the ability of the

(Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (Continued).

present selective withdrawal system to meet release temperature objectives for three proposed increased pool elevations for four study years. Subsequently, the one-dimensional numerical model was coupled with a numerical optimization routine to provide estimates for the location of additional selective withdrawal intakes required to meet specified release temperature objectives for the higher normal pools.

It was determined that four additional selective withdrawal intakes would be required to provide the flexibility necessary to maintain downstream temperature objectives. Furthermore, the additional ports (6 ft wide by 7 ft high) should be larger than the existing ports (5 ft by 5 ft) to ensure that the intakes can pass flow at a rate equal to the capacity of the wet wells.

PREFACE

The study reported herein was authorized by the Office, Chief of Engineers (OCE), U. S. Army, 16 July 1980, at the request of the U. S. Army Engineer District, Baltimore (NAB).

The investigation was conducted during the period August 1980 to January 1981 in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES) under the direction of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, J. L. Grace, Jr., Chief of the Hydraulic Structures Division, and Dr. D. R. Smith, Chief of the Reservoir Water Quality Branch (Physical). The study was conducted by Mr. J. P. Holland with some assistance from Mr. B. Loftis. The report, prepared by Mr. Holland with assistance from Ms. B. R. Turner, was reviewed by Mr. Grace and Dr. Smith.

Commanders and Directors of WES during the conduct of this study and the preparation and publication of this report were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acre-feet	1233.482	cubic metres
acres	4046.856	square metres
Btu (International Table)	1055.056	joules
cubic feet per second	0.02831685	cubic metres per second
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
feet per second	0.3048	metres per second
feet per second per second	0.3048	metres per second per second
miles (U. S. statute)	1.609344	kilometres
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
square feet	0.09290304	square metres
square miles (U. S. statute)	2.589988	square kilometres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

EFFECTS OF STORAGE REALLOCATION ON THERMAL CHARACTERISTICS OF COWANESQUE LAKE, PENNSYLVANIA

Numerical Model Investigation

PART I: INTRODUCTION

Background and Purpose

1. Growing consumptive use of water in the Susquehanna River Basin has resulted in several users expressing an interest in purchasing water supply storage in Cowanesque Lake, a project which is nearing the filling stage of construction. The lake, as originally planned, has no water supply storage. The U. S. Army Engineer District, Baltimore (NAB), is examining the feasibility of reallocating some flood-control storage of Cowanesque Lake to water supply. This reallocation would result in a substantial increase in normal pool (30 to 40 ft*) elevation which may alter the thermal structure of the lake. Consequently, present selective withdrawal capabilities may prove inadequate. The purpose, then, of this study is twofold. The first is the investigation of the temperature structure expected in Cowanesque Lake after the normal pool is increased following reallocation of some flood-control storage to water supply storage within the existing project. The second purpose of the study is the location of additional selective withdrawal intakes that would allow operation of the system to satisfy downstream warmwater temperature objectives.

Project Description

2. The Cowanesque Lake project is located on the Cowanesque River approximately 2.2 miles upstream of its confluence with the Tioga River

---

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

at Lawrenceville, Pennsylvania, and approximately 12 miles south of Corning, New York, as shown in Figure 1. Cowanesque Dam, which is of rolled earth and rock-fill construction, is 3100 ft in length with a crown 151 ft above the streambed. At the dam there is a drainage area of 298 square miles. The project was designed to impound water primarily for flood control. Recreational use was also authorized.

3. When the lake is at the elevation of the spillway crest, el 1117.0,* it will extend approximately 8.0 miles upstream and will have a surface area of approximately 2060 acres. For the initially designed normal recreation pool (el 1045.0), the lake has a maximum depth of 45 ft and extends 4.2 miles upstream with a surface area of 410 acres.

4. Releases from the lake will be made through an outlet works with an outlet tunnel whose cross-sectional area is 139 sq ft and over a 400-ft-long emergency spillway. The outlet works tunnel is excavated through rock under the right abutment of the dam. The outlet works presently consist of an intake control tower with provisions for making selective withdrawal and flood releases. Flood releases through the outlet works will be controlled by two 6-ft-wide by 14-ft-high, hydraulically operated, slide-type service gates. The selective withdrawal releases will pass through two identical wet wells, each housing two 5.0- by 5.0-ft intakes, one at center-line el 1014.5 and one at center-line el 1037.0. All four intakes discharge into the front face of their respective wet well. The flow from each wet well will be controlled by 2-ft-wide by 4-ft-high, hydraulically operated slide gates located in separate passages on both sides of the flood-control passages, downstream of the service gates. These slide gates are at center-line el 1014.0. Each intake will pass a maximum of 250 cfs at normal pool (el 1045.0).

Approach

5. This study was accomplished with the use of numerical modeling. The approach involved the selection of several study years and simulation

* All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

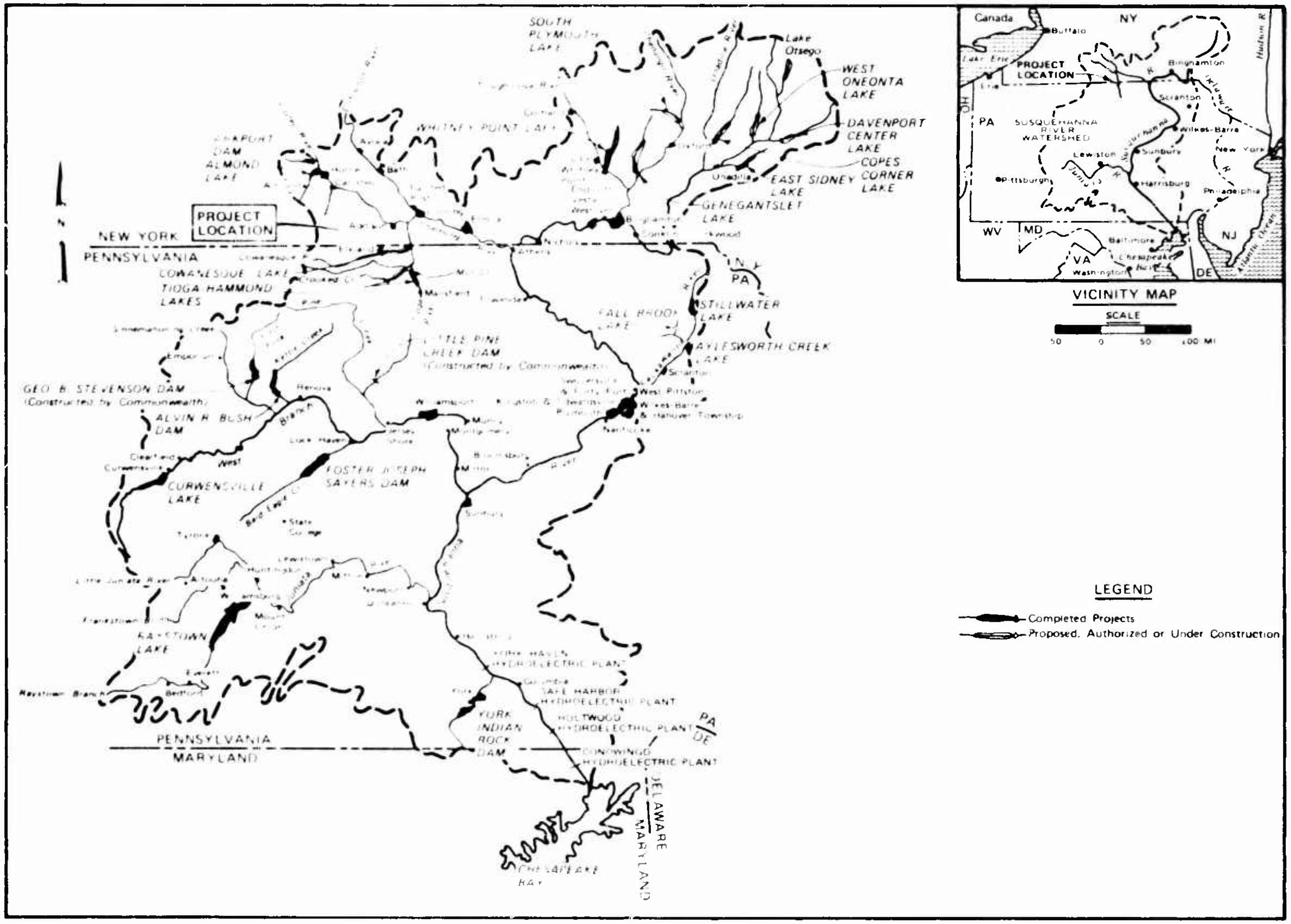

Figure 1. Location and vicinity maps

of lake operation for each of these years. Study years selected had combinations of streamflow quantities and air temperatures that could create varying conditions of thermal stratification. The input data required by the model were lake inflows and outflows, inflow stream temperatures, meteorological conditions for each of the study years, geometry of the lake, and geometry of the intake structure.

6. The heat transfer into and out of the lake was evaluated and the heat was distributed within the lake. A heat budget was computed continuously throughout each simulation period. An objective temperature was specified for each day, and an operating scheme was determined to best achieve that objective. The operation scheme for any day was the combination of open ports that minimized the difference between the objective downstream temperature and the predicted release temperature. The output from the computations included comparisons between objective and release temperatures in graphical form throughout the simulation period as well as tabular summaries for each day and plotted profiles of temperature within the lake at specified times of the year.

PART II: DISCUSSION OF NUMERICAL METHODOLOGY

7. Location of additional selective withdrawal intakes for the Cowanesque Lake thermal study was accomplished through use of a hybrid numerical approach which involved the coupling of a thermal simulation model with a mathematical optimizer. An overview of the components of this numerical approach appears below.

Thermal Model Description

8. The downstream release temperatures and the in-lake temperature characteristics for Cowanesque Lake were predicted using a thermal simulation model. The model (WESTEX)* used in conjunction with this investigation was developed at the U. S. Army Engineer Waterways Experiment Station (WES) based on the results of Clay and Fruh (1970), Edinger and Geyer (1965), Dake and Harleman (1966), and Bohan and Grace (1973).

9. The WESTEX model provides a procedure for examining the balance of thermal energy imposed on an impoundment. This energy balance and lake hydrodynamic phenomena are used to map vertical profiles of temperature in the time domain. The model includes computational methods for simulating heat transfer at the air-water interface, heat advection due to inflow and outflow, and internal dispersion of thermal energy. These computational components require various hydrological and meteorological data that are explained in the following paragraphs. A thorough discussion of the WESTEX model appears in Appendix A.

Development of Thermal Model Inputs

10. As stated in the previous paragraph, the WESTEX thermal model requires input data for lake inflows and outflows, inflow stream temperature, and various meteorological conditions. Further, calibration of the model requires a determination of the appropriate surface exchange

* Bruce Loftis, "WESTEX-A Reservoir Heat Budget Model" (first draft).

and internal mixing coefficients. This calibration procedure and the various inputs to the thermal model are described below for the Cowanesque study.

Study Years

11. The years studied in this investigation were specified by NAB as follows:

- a. 1958 - high-flow year.
- b. 1964 - low-flow year.
- c. 1966 - low-flow year.
- d. 1967 - average-flow year.

Simulations were run from March through October for each of these years. In general, it is this period in which density stratification occurs.

Meteorology

12. Meteorological data from Williamsport, Pennsylvania, Class A Weather Station were obtained from the National Oceanic and Atmospheric Administration for use in this study. Williamsport is approximately 40 miles south of the Cowanesque project. The required data consist of dry bulb and dewpoint temperatures, wind speed, and cloud cover. Daily average values were computed for each and used to determine equilibrium temperatures, surface heat exchange coefficients, and daily average solar radiation quantities for the period of record. NAB supplied these three parameters for 1958, 1966, and 1967; 1964 values were computed at WES.

Hydrology

13. Hydrologic routings were conducted by NAB to determine expected daily inflow and outflow quantities. These are shown in Plates 1A and 1B for each of the study years. Outflows for the low-flow years of 1964 and 1966 included augmented low-flow releases in order to meet water supply constraints downstream; 1958 and 1967 required no augmented releases for water supply.

Lake Geometry

14. The area-capacity curve for Cowanesque Lake is shown in Figure 2. This curve and other data describing the location and design of the intake structure were furnished by NAB.

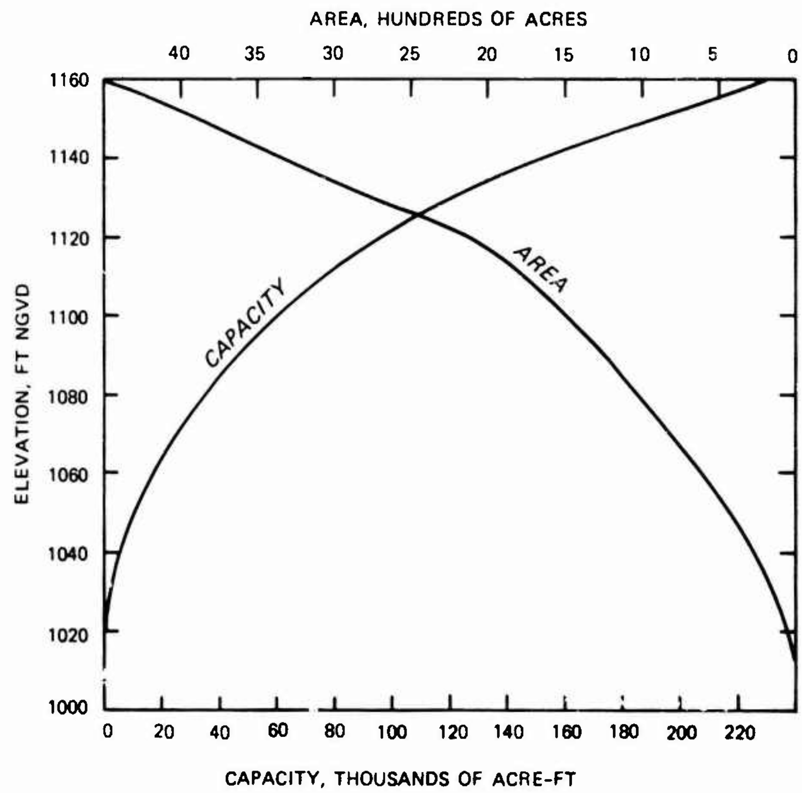

Figure 2. Area-capacity curve

Natural Downstream Temperature

15. In order to establish a natural downstream temperature objective, NAB performed a least squares curve fit to the observed stream temperatures for all years of record. The resulting equation was

$$\theta = A \sin (Bt + C) + D \tag{1}$$

where

θ = natural stream temperature objective on day t, °F

t = calendar day of year

A = -21.685

B = 0.0172

C = 1.0908

D = 52.579

Model Calibration

16. The WESTEX model requires the determination of coefficients of surface heat exchange distribution and internal mixing. For Cowanesque Lake these coefficients were determined by conducting simulations with Cowanesque hydrologic and meteorologic data. Coefficients were adjusted and simulation was repeated until the predicted temperature profiles corresponded in shape and range to those observed by NAB personnel in North Central Pennsylvania lakes of similar size, depth, and flow magnitude. The following coefficients were determined from the analysis:

$$\beta = 0.5$$
$$\lambda = 0.17$$
$$\alpha_1 = 0.30$$
$$\alpha_2 = 0.20$$

where

β = percentage of incoming shortwave radiation absorbed in surface layer

λ = light extinction coefficient, ft^{-1}

α_1 = mixing coefficient at surface

α_2 = mixing coefficient at bottom

The λ , β , and α_1 values were found to agree very well with the values used in the thermal simulation model study of Kinzua Lake (Dortch 1981), a project in the same geographical area.

Formulation of Port Location Procedure

17. The principal objective of the Cowanesque Lake thermal study was to determine the location of additional selective withdrawal intakes in order to meet a specified downstream warmwater objective. To achieve this objective, an optimization algorithm was coupled with the WESTEX model to predict the optimum port elevations for a given set of constraints. These "optimum" elevations are the set of port locations whose operation yielded the minimum difference between predicted release and objective temperatures over the simulated period. The optimum combination of port elevations was defined as that which would result in the minimum objective function. The objective function selected basically consisted of the sum of squared deviations between the computed release and objective temperatures. The components of the port location procedure are described in the following sections.

Port Location Procedure

18. For each individual operating condition, the location of additional selective withdrawal intakes was accomplished through a sequential process. This process involved estimation of the optimum intake configuration for downstream temperature maintenance, prediction of downstream release characteristics resulting from operation of this intake configuration, and computation of an objective function (described in paragraph 19). This process was repeated until a minimum value for the objective function was obtained, at which point the estimated location of the selective withdrawal intakes was defined as the "optimum" location for maintenance of downstream temperature objectives. Although this procedure could be accomplished manually, an optimization routine was used to locate an estimate to the "optimum" selective withdrawal configuration for each operating condition. The port location procedure used in this study is described in detail in Appendix B.

Development of Objective Function

19. The principal purpose of this study was to determine the

location of additional selective withdrawal intakes to meet specified downstream warmwater temperature objectives. An objective function is a scalar index that provides an indication of how good one possible decision (i.e., location estimate) is in meeting these given objectives. Minimization of this objective function yields the optimal location of these additional ports for release temperature control.

20. The objective function used for Cowanesque Lake is the sum of several terms. Two terms are weighted portions of the sum of squares of deviations between predicted release and target temperatures. The principal term represents the contribution of the squared temperature deviation on days when the absolute value of the deviation (predicted release temperature from target temperature) is greater than 2.78°C (5°F). This portion has physical significance in that the State of Pennsylvania requires releases from Cowanesque Lake to be plus or minus 2.78°C (5°F) from the natural stream temperature (which is the study objective). A number of other objective function terms, which were added to enhance numerical uniqueness and reflect physical constraints, are described in Appendix B.

PART III: NUMERICAL SIMULATIONS

21. A broad range of conditions was simulated during the Cowanesque study. Simulations were conducted for normal pool elevations 1075.0, 1080.0, and 1085.0 for each of four study years (1958, 1964, 1966, and 1967). The three pools represent probable normal pools following reallocation of a portion of flood-control storage to water supply storage.

22. In addition to these simulated years and pools, NAB presently has three possible schemes for the operation of the Cowanesque project for water supply releases. These three schemes, or "scenarios," represent allocation of water supply releases for differing consumers downstream. The three scenarios are characterized by the following flow targets downstream:

Scenario 1 - 50 cfs target at Wilkes-Barre, Pa.

Scenario 2 - 45 cfs target at Harrisburg, Pa.

Scenario 3 - 50 cfs target at Wilkes-Barre, Pa.
45 cfs target at Harrisburg, Pa.

These three scenarios were simulated for each pool for the 1964 study year. Only Scenario 2 was simulated for 1966, as requested by NAB. Study years 1958 and 1967 (average- and high-flow years, respectively) required no water supply releases.

23. Simulations of each combination of pool, year, and scenario were made for each of the three normal pools with operation of the existing selective withdrawal intake configuration. Since these simulations showed temperature objectives would not be met, additional withdrawal ports were studied. Analysis by NAB personnel indicated that up to three additional ports could be placed in each of two wet wells at the Cowanesque project. Thus, up to six separate port locations could be sited in addition to those existing in order to meet specified constraints. Analogous simulations incorporating additions to the existing selective withdrawal system were then run.

24. The geometry of these additional ports was another decision

variable. Ports sized the same as those presently in place at Cowanesque, 5 ft wide by 5 ft high (hereafter referred to as small), were used for most of this study. Ports 6 ft wide by 7 ft high (hereafter referred to as large), which allowed additional selective withdrawal capacity beyond that of the small ports, were also analyzed.

25. Discussion of these various simulations appears in PART IV.

PART IV: DISCUSSION OF RESULTS FOR SIMULATION-SPECIFIC CONDITIONS

26. As discussed in PART III, a broad range of conditions was simulated during the Cowanesque study. Combinations of differing pool elevations, study years, port geometry and number, and release scenarios were simulated. For each of these combinations, an "optimum" intake configuration for that specific combination was found. This PART discusses results from simulation of these "specific" port configurations. Of primary importance in this discussion are the number and location of additional intakes required for each simulation to meet the specified downstream temperature objective. These results may be divided into the following areas:

<u>a</u>. No additional ports added to the existing system.

<u>b</u>. One additional level of ports added to the existing system.

<u>c</u>. Two additional levels of ports added to the existing system.

Coupled with the discussion of the number and location of additional ports is the presentation of simulation results for specific conditions relating the effects of both release "scenario" strategies and larger port geometry on downstream temperature maintenance. Selective withdrawal system flexibility requirements for the specific conditions simulated are discussed at the end of this PART.

No Additional Ports

27. Operation of the present selective withdrawal configuration (hereafter referred to as 0-levels) for each pool, year, and release scenario combination was simulated. Results of these simulations, shown graphically as plots of daily release temperature in Plates 2A-2C, show the inadequacy of the present system to meet the specified downstream temperature objective. The two solid, smooth curves on each plot trace the boundary of the ±2.78°C (±5°F) band around the natural stream temperature

objective. The release temperatures resulting from operation of the present selective withdrawal system were generally outside this ±2.78°C band from late spring to late summer for each year. The number of days the daily release temperature violated this band appears in Table 1 for each simulation. A minimum of 100 violation days was computed for the present system.

One Additional Level

28. The inadequacy of the present selective withdrawal system to meet downstream temperature objectives prompted investigation of additional port elevations in order to meet the warmwater temperature objective. Initial attempts to locate additional ports showed that the siting of one port level (two ports at the same elevation, one port per wet well) was efficient in meeting downstream objectives. Results from simulation of the Cowanesque selective withdrawal system with one additional level of 5-ft-wide by 5-ft-high ports (referred to as 1-level small ports in this section) are presented graphically in Plates 2A-2C. A summary of the center-line* elevations of the additional level intakes, as well as the number of days temperatures released through this system violated the ±2.78°C objective band, appears in Table 2. As indicated in Plates 2A-2C, the addition of one level of small ports placed at the "optimum locations" of Table 2 provided vast improvement in the ability of the selective withdrawal system to meet the specified downstream temperature objective when compared with operation of the existing system. Release temperatures are rarely outside the objective temperature band following addition of a single level of small ports. When the predicted temperature is outside the objective band, it is usually cooler than the objective. As shown in Table 2, the average difference between release and objective temperatures is consistently negative. The duration of these occurrences is generally small, typically on the order of 10 days

* All port elevations in this and subsequent sections are port center-line elevations.

or less. The magnitude and duration of these release temperature deviations are presented graphically in Plates 3A-3C. Plotted on these plates are the algebraic differences between the predicted release temperature and the objective temperature for each simulated day.

29. The discussion presented above was for the results of simulation of one additional level of ports located at the elevations given in Table 2. These "optimum" port elevations should not, however, be construed as "absolute" with respect to maintenance of the given downstream temperature objective. For the set of conditions simulated, a range of center-line elevations exists over which little change in predicted release temperature occurs. This is indicated in plots of the objective function (described in paragraph 19) as a function of port level elevation as shown in Plates 4A-4C. For each condition a range of center-line intake elevations exists over which little change in the objective function value around the minimum value is noted. In general, for years with no water supply releases and little pool fluctuation (1958 and 1967), this flat range in the function is found for port elevations from near the normal pool water surface to approximately 10 ft below the normal pool (approximately the minimum thickness of the epilimnion, the upper, warmwater layer, for the simulation period). For 1964 and 1966, years with water supply releases, this range runs from approximately 10 ft below to approximately 20 ft below the elevation of the normal pool water-surface elevation. Thus, for each simulation there is approximately a minimum 10-ft range in which the center-line elevation of the additional selective withdrawal intake level may be placed without a loss in system ability to meet downstream temperature objectives.

Two Additional Levels

30. For the simulated conditions, a single level of ports strategically located in the pool resulted in a selective withdrawal design that would usually release water within the desired temperature band. When the release temperature was outside the objective band it was consistently too cold. In general, to improve temperature maintenance with

a second level of additional ports, it would be necessary to site the second level above the elevation of the optimum single level locations (shown in Table 2) so that more warm water could be withdrawn. This approach was employed in the evaluation of the addition of a second level port to meet the desired warmwater objective.

31. For all pool elevations investigated for 1958 and 1967 and for the el 1075.0 pool of 1964 (all three scenarios), no improvement in meeting the temperature objective was indicated by the addition of two port level elevations as compared with one. An analysis of the meteorological and hydrological data for these simulations helps to explain this conclusion. In the spring, when both warm temperatures and warm intermediate inflows would normally promote the blending of water from the upper layers, the high outflows simulated significantly exceeded the capacity of the selective withdrawal system, thereby requiring the release of cold bottom waters from the floodgates. The location of a greater number of additional intakes was precluded by the effects of thermal blockage which reduces or negates flow control of individual intakes which are operating simultaneously in the same wet well. Further, during the summer the simulated outflows did not exceed the selective withdrawal capacity of a single level of intakes. As a result, only one additional level of intakes was required to produce release temperatures consistent with downstream summer temperature objectives for these simulations.

32. A lack of improvement in temperature maintenance with the addition of a second port level as described above was also noted for the 1075.0 pool elevation for 1966. The lack of improvement, however, was not related to those causes described above. The specific meteorological and hydrological conditions of 1966, coupled with the 1075.0 pool elevation, resulted in little difference between the temperature near the water surface and optimum single port level. The low spring outflows were generally less than the selective withdrawal capacity of a single level of intake. Thus, no improvement in release quality was predicted through the operation of a second additional port.

33. For the simulations of 1964 (all three scenarios) and 1966 in which the pool elevations were 1080.0 and 1085.0, there was an improvement in the ability of the selective withdrawal system to meet the downstream temperature objective through the use of two additional levels of intakes as compared with a single level. Improvement occurred during the midspring period (mid-May to early June). During this period, before the onset of water supply releases, the pool remains steady at el 1085.0 or el 1080.0 for the respective study year. In each case, meteorological and hydrological conditions produced a thermal profile which was generally 1 to 2.5°C warmer near the surface than at the elevation of the optimum single level location. For respective simulated conditions, the optimum single port location was approximately 10 to 20 ft below the normal pool elevation to compensate for summer pool drawdown. For the flow conditions simulated, ports located 10 to 20 ft (center-line elevation) below the normal pool surface did not withdraw adequate quantities of warm epilimnetic waters during the spring period, while ports located near the normal pool surface could withdraw these waters.

Scenario Differences

34. NAB designated three water supply release strategies, or scenarios, as described in paragraph 22. Of the years studied, all three scenarios were used only in 1964. Plots of both daily release temperature and deviation of this temperature from the objective for 1964 appear in Plates 2A-2C and 3A-3C, respectively. Examination of these plates revealed no significant difference in the thermal characteristics of Cowanesque Lake releases as a result of the differing 1964 release strategies of Scenarios 1, 2, and 3. Further, no difference in the location of additional upper-pool port levels, or in the objective function values, was noted among the scenarios. Because differences between the scenarios were considered minor, only Scenario 3 was run for 1964 during the remainder of the study.

Large Port Geometry

35. Examination of the release temperature deviations incurred through the use of the optimum port configuration for a specific simulation condition revealed a strong correlation between large release temperature deviations and the release of flows in excess of the selective withdrawal system capacity. To minimize these deviations, the capabilities of the Cowanesque selective withdrawal system should be maximized within the structural constraints of the Cowanesque intake structure. As an example, when the pool is at el 1085.0, the wet wells can pass a maximum combined flow of 700 cfs. However, due to frictional and entrance losses, a 5-ft-wide by 5-ft-high port of the type presently installed at Cowanesque will pass only 250 cfs, resulting in 500 cfs maximum for combined flow through the selective withdrawal system with these ports. Thus, only approximately 71 percent of the potential release capacity of the Cowanesque selective withdrawal system would be utilized with 5-ft-wide by 5-ft-high ports for pool elevation of 1085.0.

36. To maximize the selective withdrawal capabilities of the system, simulations were made with a single level of additional ports 6 ft wide by 7 ft high. Examination of the Cowanesque outlet works and discussion with NAB personnel indicated that this port geometry was a proper size to facilitate both the desired flow capacity and the hydraulic and structural constraints of the Cowanesque wet wells. The ports were placed at the optimum center-line location found for the 5-ft-wide by 5-ft-high single level as given by Table 2. These configurations were then simulated for each study year and pool. The selective withdrawal maximum outflow was set at 700, 670, and 640 cfs for the el 1085.0, 1080.0, and 1075.0 pools, respectively. Daily release temperature plots for these large ports are shown in Plates 5A-5C. Objective function values and the number of days of temperature violations for large port operation are given in Table 3.

37. Differences in the in-lake thermal distribution as a result of the use of large rather than small ports were also noted. Plates 6A-6X show the in situ temperature profiles expected at Cowanesque Lake for

representative simulations of both large and small ports. These profiles show that during 1958, 1964, and 1967, a 1 to 2°C cooling of the hypolimnion (bottom, cold water layer) was predicted through the use of large ports when compared with similar small port operation. This results from the release of larger quantities of epilimnion waters in late spring by the 6-ft-wide by 7-ft-high ports than by the smaller ports. Larger epilimnion release, in turn, resulted in the release of smaller amounts of hypolimnion waters through the floodgate. Thus, cold hypolimnion waters that would have been released and subsequently replaced by warmer waters from higher in the pool remain within the pool when the large ports are used. This cooling trend remains in effect throughout the majority of the simulation period, resulting in warmer bottom temperatures through use of the 5-ft-wide by 5-ft-high ports than through use of the larger counterpart. Surface temperatures, however, are consistently the same for both port types. The 1966 study year had no large spring flows, as observed in the other study years, which necessitated hypolimnion releases. Thus, the operational schemes of both the 6-ft-wide by 7-ft-high ports and the 5-ft-wide by 5-ft-high ports were identical for the period, and the cooling effect described above was not observed for 1966.

38. The impact to aquatic biota as a result of the in-lake cooling experienced by large port use relative to small port use is beyond the scope of this work. If this in-lake cooling can be accepted, the use of larger port geometries of a size capable of meeting the maximum selective withdrawal capacity and the physical constraints of the Cowanesque wet wells seems warranted. The improvements in meeting the downstream objective through use of the large ports may outweigh predicted degradations in the lake. Further, the larger vertical dimension of the 6-ft-wide by 7-ft-high ports would allow greater flexibility in both fully and partially submerged operation. This flexibility would be of great importance during periods with large pool fluctuations such as those of 1964.

Multiport Flexibility

39. Although one level of additional selective withdrawal intakes

is generally adequate to meet downstream temperature objectives for each of the specific combinations considered, there are conditions when a single level located at the optimum elevation does not effectively maintain temperature objectives. In instances where the optimum single level of ports was located 10 to 20 ft below the normal pool elevation, such as 1964 or 1966, test results showed that an additional port level located high in the epilimnion would result in improvement to spring release temperature maintenance beyond that of a single level lower in the pool. Further, due to the relatively small incremental volumes of Cowanesque Lake, large net inflows will result in a substantial increase in pool elevation. Routings for 1964 indicate that a net inflow of 13,100 cfs (on day 65) would result in an increase of approximately 20 ft in the pool. The location of a level of ports near the normal pool water surface in addition to those located at a lower optimum single elevation would facilitate the meeting of downstream temperature at increased pool elevations.

40. Instances may also exist wherein an optimum single level of ports located near the normal pool elevation (as in 1958 and 1967) would not effectively maintain release temperature objectives. Large pool drawdown, such as that for 1964, would render a level of ports located near the normal pool water surface inoperative over a large portion of the simulation period. This action would result in very inefficient release of epilimnion waters due to the depth of the highest existing port level (el 1037.0), thereby increasing the magnitude and frequency of temperature violations. Further, flexibility would also be needed during periods of filling when a single level of ports high in the pool would preclude epilimnetic release by selective withdrawal prior to port submergence. Intermediate ports to this upper level of intakes and those existing are requisite to system flexibility during filling.

PART V: OPTIMUM MULTIPORT CONFIGURATION

41. In PART IV, results were presented which showed that a single additional set of intakes located strategically in the pool would generally provide adequate downstream temperature maintenance for the specific conditions simulated. However, results also indicated that conditions can exist which necessitate the location of two sets of additional intakes rather than a single additional set. If two sets of intakes are added to the present system, selective withdrawal system flexibility for a given year and normal pool elevation could then be substantially enhanced through use of multiple port elevations with the following port scheme:

- a. Two large ports (one level) located high in the epilimnion in a given specific range for the normal pool and year simulated.
- b. One large port located at the elevation of the optimum 1964 single intake level for the given normal pool (shown in Table 2).
- c. One large port located 10 ft below the optimum 1964 elevation of b.
- d. Small ports of the existing system.

The lower additional ports (described in b and c above) would be used only during periods of extreme pool drawdown. In general, the releases simulated during these drawdown periods were less than the maximum selective withdrawal flow (350 cfs) through a single large port. Therefore, single large ports located at each of these two elevations for a specified pool would be adequate to pass the simulated outflows.

42. The placement of the additional ports in the manner described above would result in the following:

- a. System flexibility would be increased for all normal pools simulated for 1964. Placement of the highest additional intakes in the epilimnion of the pool would help reduce spring release temperature degradations. Placement of an additional intake near the optimum single elevation for the given normal pool would result, by definition, in the minimum release temperature deviation from the objective for the bulk of the simulation period.

b. Placement of an additional intake near the optimum 1964 single elevation would allow the highest additional level of intakes for the 1080.0 and 1075.0 pools of 1966 to be placed higher in the pool than their optimum single level elevations. Results indicated that the highest additional level could be placed 2 and 4.5 ft above the optimum 1966 single level elevation (center-line el 1071.4 and el 1066.0 for pool elevations 1080.0 and 1075.0, respectively) with no loss in temperature maintenance for these pool elevations, respectively.

c. Epilimnetic releases of at least 350 cfs could be achieved for all pool elevations between the normal operating pool elevation and an elevation 25 ft below. Thus, a 25-ft drawdown (which was exceeded only once in this study) could be incurred with little loss in selective withdrawal efficiency for outflows less than 350 cfs.

Pool-Specific Optimum Multiport Configuration

43. Locating four additional ports in the manner described in paragraph 41 results in changing the range of elevations over which the highest level of additional ports could be located. This range is given for both the addition of a single level of ports and the addition of four ports (as described in paragraph 41) in Table 4. As stated in paragraph 42, the range is extended for the 1080.0 and 1075.0 pools of 1966 and all pools for 1964. A consequence of this broadened range for the two low-flow years is that port locations can be selected which are common to all conditions simulated for a given normal pool elevation. Table 4 shows that the optimum four-port configuration which is common to all study years for each of the three normal pools consists of the following:

a. 1085.0 pool.

Two intakes located between el 1075.0 and el 1077.0.

One port located at el 1067.0.

One port located at el 1057.0.

Intakes of existing system (two ports at el 1037.0, two at el 1014.5).

b. 1080.0 pool.

Two intakes located between el 1070.0 and el 1073.5.

One port located at el 1063.0.

One port located at el 1053.0.

Intakes of existing system.

c. 1075.0 pool.

Two intakes located between el 1065.0 and el 1071.5.

One port located at el 1062.0.

One port located at el 1052.0.

Intakes of existing system.

If the upper level of intakes is located at el 1065.0 for the 1075.0 pool, the port at el 1062.0 could be placed at el 1052.0 or removed with little loss of selective withdrawal efficiency for conditions simulated. It should be noted that all ports except those existing were assumed to be 6 ft wide by 7 ft high.

Optimum Port Configuration for All Pool Elevations

44. If the normal operating pool elevation is known to be a specific pool from among the three studied, the selective withdrawal configuration outlined in the previous paragraph for the particular pool would be an optimum scheme for temperature maintenance downstream. If this normal pool elevation is not well defined, or if the normal pool elevation is later changed, a selective withdrawal system designed for a specific pool elevation could prove inadequate. An example of such action would be the change in normal pool elevation from el 1085.0 to el 1075.0 which would leave the highest level of ports inoperative over a large portion of the simulation period. Thus, the possibility of one single configuration of intakes which could be operated optimally for temperature maintenance for all of the conditions studied was investigated. Determination of this configuration (which was to consist of four large ports in addition to those existing) was begun by selecting an optimum elevation for the highest additional level of ports which was common to all pool/year conditions. This elevation was determined by examining the range of optimum center-line elevations given in Table 4 for the highest additional ports for each pool/year condition with only

a single level of ports added. Results for the addition of a single level of ports rather than those for the addition of four ports were considered because the latter results were based on locations for the third and fourth additional ports which were pool-specific and thus contrary to this effort. Examination of Table 4 shows that a common range of optimum center-line elvations for the highest additional ports extends from el 1070.0 to el 1071.4 for all conditions simulated except the 1958/1085.0 pool combination and the 1075.0 pool combinations of 1964 and 1966. The upper end of the range, el 1071.4, was chosen for the elevation of the highest additional intakes. Two additional intakes, one each at el 1062.0 and el 1052.0, were then sited for additional flexibility. This configuration is also one of the optimum four-port configurations for the 1075.0 pool (described in paragraph 43) and, as such, will be quite adequate at meeting downstream objectives for the 1075.0 pool combinations of 1964 and 1966. Representative results, Table 5 and Plates 7A-7C and 8A-8X, show that with the exception of the 1958/1085.0 pool, this system is capable of meeting downstream temperature objectives at least as well as the optimum port configuration for any of the specific year/pool elevation combinations. For hydrological and meteorological conditions similar to those simulated in this study, this single configuration of ports is generally adequate to meet downstream temperature constraints.

45. The 1958/1085.0 pool results indicate the limits of this configuration. Location of the upper port level at el 1071.4 did not allow adequate withdrawal of epilimnetic waters for 1958 (the high inflow, high outflow year). This occurred because the majority of the epilimnion rose above the effective withdrawal limit of the 1071.4 port elevation. However, it should be noted that no selective withdrawal configuration simulated was highly efficient in meeting downstream temperature objectives for the high inflow/outflow conditions of 1958. The upper intake level at el 1071.4 is within the epilimnion for all other simulated conditions, and no temperature deviation in excess of that expected with a "pool-specific" configuration should be expected. Thus, with the exception of high-flow years, a single combination of port locations may

be used to meet the desired temperature objective for all conditions similiar to those modeled.

Selective Withdrawal Capacity

46. The capacity of the selective withdrawal system at Cowanesque Lake is 700 cfs at el 1085.0 normal pool. While this capacity is generally adequate, hydrologic events during the spring of three of the study years (1966 excluded) resulted in an extended period wherein the capacity of the selective withdrawal system was inadequate to meet the downstream objective. NAB has indicated that it plans to maintain a maximum normal pool at el 1085.0 and that storage above this elevation will be quickly released. If the releases from the top ports are at a maximum, 700 cfs, any additional flow must be released from the floodgate. This flow, which is extremely cold in the spring, may cause a temperature deviation in the spring of up to 2°C over a one-day time-step for a floodgate flow as little as 300 cfs. Any upgrading of the selective withdrawal capacity would be beneficial. The Cowanesque system seems especially sensitive to bottom releases in the spring, and this increase in selective withdrawal capacity may merit consideration.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

47. A numerical simulation model in connection with a mathematical optimizer has been used to locate additional selective withdrawal intakes at Cowanesque Lake. These additional intakes will be needed in order to meet a specified downstream warmwater temperature objective following increases in normal pool elevation as a result of proposed reallocation of some flood-control storage to water supply storage. Operation of the present selective withdrawal system showed the system to be inadequate in meeting temperature objectives under increased pool elevation conditions. Simulations indicated that a single level of additional ports, whose center-line elevations were located from near the normal pool water surface to approximately 10 ft below that water surface, was adequate (except during extremely high inflow periods) to meet downstream objectives for study years 1967 and 1958 (average- and high-flow years, respectively). The upper bound of this 10-ft region was approximately 10 ft below the normal pool water surface for study years 1964 and 1966 (low-flow years).

48. Simulation indicated that the majority of temperature deviations observed occurred when the outflow was in excess of the selective withdrawal capacity. The use of larger ports (6 ft wide by 7 ft high) allowed an increase in the selective withdrawal capacity from its present 500 cfs (as constrained by the 5-ft-wide by 5-ft-high existing ports) to 700 cfs. Either improved or unchanged temperature deviations were generally noted through use of the larger port size for the additional intakes when compared with the 5-ft-wide by 5-ft-high ports.

49. Results from various simulations indicated a need for a second set of additional intakes. These intakes would allow a vastly more flexible selective withdrawal system than a single level of additional intakes would afford. This flexibility would be required during periods of highly fluctuating pool elevations. Further flexibility would be needed during the filling process, when a single additional port level located high above the bottom would not provide the necessary selective withdrawal capabilities for pool elevations between its elevation and

the elevation of the highest existing ports (el 1037.0).

50. It is recommended that two additional sets of 6-ft-wide by 7-ft-high selective withdrawal intakes be added to the existing ports in the Cowanesque Dam outlet works. If the normal operating pool elevation is known from the three elevations studied, it is recommended that two upper level intakes be placed with their center lines approximately 3 to 10 ft below the elevation of that water surface. Placement of additional 6-ft-wide by 7-ft-high ports at the optimum single level location corresponding to 1964 conditions with the normal pool under consideration would allow a common range of optimum upper level elevations to exist for all simulations of a given pool. If the hydrologic conditions simulated in this study are representative (spring storm events, small summer outflows during periods of lake drawdown), a single port at the 1964 optimum location would suffice. The fourth additional 6-ft-wide by 7-ft-high port could then be placed with a center line 10 ft below the 1064.0 single-level optimum elevation to extend system flexibility.

51. If the normal operating pool cannot be defined at this time, or if the normal pool might be changed later, a different intake configuration is suggested. This configuration is:

- a. Two large ports (one level) at el 1071.4
- b. Single large port at el 1062.0
- c. Single large port at el 1052.0
- d. Ports of the existing system

where all port elevations are center-line elevations. The upper intake level may not withdraw sufficient warm waters from the epilimnion during high-flow years. High-flow years in combination with a 1085.0 pool, or other hydrological and meteorological factors not specifically simulated in this study, could negate the effectiveness of this alternate configuration. If the simulated hydrological and meteorological conditions are representative, then this system is quite adequate for all pools and years simulated except the combination of high inflow years with a normal pool at el 1085.0.

52. Regardless of the intake configuration, it is recommended that all additional intakes located at Cowanesque Lake be of sufficient

dimension to pass the maximum selective withdrawal capacity attainable for the pools studied, 700 cfs. This selective withdrawal capacity may still be inadequate for spring outflows of as little as 300 cfs in excess of the present selective withdrawal capacity.

53. The simulations for all pools of the 1958 study year (high flow) showed a marked inability to meet downstream temperature objectives in the spring season. A period of spring temperature violations was also noted for 1967 (average flow). These violations are a result of a combination of factors. The selective withdrawal capacity at Cowanesque Lake, as discussed in the previous paragraph, is often too small to release the required flow. Secondly, there were periods in mid-spring, such as in 1958, when no large quantities of warm water existed in the Cowanesque pool. Both of these factors are contributors to release temperature violations during periods of high spring outflow. Outflow not withdrawn through upper pool outlets is released through the floodgates. Release of this very cold hypolimnetic water drives the release temperature well below that of the upper pool temperatures. The 1967 violations were of this nature. When extremely high inflow and outflow conditions are coupled with extremely cold inflow temperatures, the ability of the present Cowanesque selective withdrawal system to meet a specified release temperature is further lessened. The severity and duration of the release temperature deviations observed for 1958 are an example.

REFERENCES

Bohan, J. P., and Grace, J. L., Jr. 1973 (Mar). "Selective Withdrawal from Man-Made Lakes; Hydraulic Laboratory Investigation," Technical Report H-73-4, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Clay, H. M., Jr., and Fruh, E. G. 1970. "Selective Withdrawal at Lake Livingston; An Impoundment Water Quality Model Emphasizing Selective Withdrawal," Progress Report EHE 70-18 (CRWR 66), Environmental Health Engineering Research Laboratory, University of Texas, Austin, Tex.

Dake, J. M. K., and Harleman, D. R. F. 1966. "An Analytical and Experimental Investigation of Thermal Stratification in Lakes and Ponds," Technical Report No. 99, Massachusetts Institute of Technology Hydrodynamics Laboratory, Cambridge, Mass.

Dortch, M. S. 1981 (Oct). "Investigation of Release Temperatures for Kinzua Dam, Allegheny River, Pennsylvania; Hybrid Model Investigation," Technical Report HL-81-9, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Edinger, J. E., Duttweiler, D. W., and Geyer, J. C. 1968. "The Response of Water Temperature to Meteorological Conditions," <u>Water Resources Research,</u> Vol 4, No. 5, pp 1137-1143.

Edinger, J. E., and Geyer, J. C. 1965. "Heat Exchange in the Environment," Publication No. 65-902, Edison Electric Institute, New York.

Table 1

Results of Simulation of Existing Selective Withdrawal System

Year	Normal Pool Elevation ft NGVD	Scenario	Objective Function Value	Number of Days of Band Violation	Maximum Band Violation °C	Average Difference from Objective °C
1967	1085	NA*	7,140	141	9.80	-4.39
1958	1085	NA	6,558	148	9.16	-4.18
1966	1085	2	12,700	161	11.92	-5.74
1964	1085	1	6,610	139	9.52	-3.93
1964	1085	2	7,129	144	9.52	-4.19
1964	1085	3	6,550	136	9.52	-3.83
1967	1080	NA	4,500	135	8.03	-3.53
1958	1080	NA	7,139	142	10.83	-4.34
1966	1080	2	9,727	151	10.59	-4.95
1964	1080	1	4,737	119	8.36	-3.24
1964	1080	2	5,120	126	8.36	-3.46
1964	1080	3	4,729	118	8.36	-3.16
1967	1075	NA	3,184	115	7.09	-2.88
1958	1075	NA	5,554	147	10.20	-3.93
1966	1075	2	7,051	142	9.50	-4.15
1964	1075	1	3,077	100	7.15	-2.53
1964	1075	2	3,076	100	7.15	-2.53
1964	1075	3	3,077	100	7.15	-2.48

* NA denotes not applicable. No water supply releases for these years.

Table 2

Results of Simulation of Selective Withdrawal System with One Additional Level of 5- by 5-ft Ports*

Year	Normal Pool Elevation ft NGVD	Scenario	Single Optimum Port Center-Line Elevation ft NGVD	Objective Function Value	Number of Days of Band Violation	Maximum Band Violation °C	Average Difference from Objective °C
1967	1085	NA**	1075.4	241	9	6.76	-0.54
1958	1085	NA	1081.0	434	26	8.47	-1.06
1966	1085	2	1075.9	134	12	5.01	-0.58
1964	1085	1	1067.0	62	5	4.14	-0.50
1964	1085	2	1067.0	62	5	4.14	-0.50
1964	1085	3	1067.0	62	5	4.14	-0.50
1967	1080	NA	1076.4	143	8	5.21	-0.40
1958	1080	NA	1075.0	459	28	8.24	-1.13
1966	1080	2	1071.4	100	8	4.94	-0.59
1964	1080	1	1063.0	53	5	3.85	-0.39
1964	1080	2	1063.0	53	5	3.85	-0.39
1964	1080	3	1063.0	53	5	3.85	-0.39
1967	1075	NA	1070.0	115	8	4.47	-0.39
1958	1075	NA	1069.0	458	28	8.02	-1.12
1966	1075	2	1066.7	112	9	4.99	-0.60
1964	1075	1	1062.0	20	2	3.43	-0.21
1964	1075	2	1065.6	20	2	3.38	-0.23
1964	1075	3	1062.0	20	2	3.43	-0.21

* Port configuration consisted of two ports at the elevation of the single optimum, plus ports of the existing system (two ports at el 1037.0, two ports at el 1014.5).

** NA denotes not applicable. No water supply release for these years.

Table 3

Results of Simulation of Selective Withdrawal System with One Additional Level of 6- by 7-ft Ports*

Year	Normal Pool Elevation ft NGVD	Scenario	Single Optimum Port Center-Line Elevation ft NGVD	Objective Function Value	Number of Days of Band Violation	Maximum Band Violation °C	Average Difference from Objective °C
1967	1085	NA**	1075.4	128	4	6.56	-0.48
1958	1085	NA	1081.0	445	28	7.48	-1.02
1966	1085	2	1075.9	110	10	3.86	-0.57
1964	1085	3	1067.0	17	1	3.93	-0.55
1967	1080	NA	1076.4	97	4	5.60	-0.33
1958	1080	NA	1075.0	445	28	7.55	-1.07
1966	1080	2	1071.4	114	11	3.79	-0.60
1964	1080	3	1063.0	15	1	3.70	-0.41
1967	1080	NA	1070.0	80	4	4.78	-0.36
1958	1080	NA	1069.0	455	28	7.63	-1.10
1966	1080	2	1066.0†	120	11	3.96	-0.61
1964	1080	3	1062.0	12	1	3.40	-0.23

* Port configuration consisted of two ports at optimum single-level elevation plus all ports of existing system.

** NA denotes not applicable. No water supply releases during these years.

† Port dropped 0.7 ft from optimum single-level location of Table 2 to accommodate larger geometry.

Table 4

Results of Simulation of Selective Withdrawal System

with Four Additional 6- by 7-ft Ports*

Year	Normal Pool Elevation ft NGVD	Scenario	Center-Line Elevation ft NGVD: Two Highest Ports	Third Port	Fourth Port	Range of Optimum Center-Line Elevations for Highest Additional Ports, ft NGVD: Single Level Only Sited		Four Ports Sited	
							to		to
1967	1085	NA**	1075.5	1067.0	1057.0	1067.0	1081.5	1067.0	1081.5
1958	1085	NA	1081.0	1067.0	1057.0	1075.0	1081.5	1075.0	1081.5
1966	1085	2	1075.9	1067.0	1057.0	1070.0	1076.5	1070.0	1077.0
1964	1085	3	1067.0	1067.0	1057.0	1064.0	1075.0	1064.0	1081.5
1967	1080	NA	1076.4	1063.0	1053.0	1060.0	1076.5	1060.0	1076.5
1958	1080	NA	1075.0	1063.0	1053.0	1070.0	1076.5	1070.0	1076.5
1966	1080	2	1071.4	1063.0	1053.0	1065.0	1071.4	1065.0	1073.5
1964	1080	3	1063.0	1063.0	1053.0	1060.0	1073.0	1060.0	1076.5
1967	1075	NA	1070.0	1062.0	1052.0	1055.0	1071.5	1055.0	1071.5
1958	1075	NA	1069.0	1062.0	1052.0	1065.0	1071.5	1065.0	1071.5
1966	1075	2	1066.0	1062.0	1052.0	1060.0	1067.0	1060.0	1071.5
1964	1075	3	1062.0	1062.0	1052.0	1055.0	1066.0	1055.0	1071.5

* Port configuration simulated consisted of two large ports at elevation of two highest ports, single large port at elevation of third port, single large port at elevation of fourth port, and all small ports of existing system.

** NA denotes not applicable. No water supply releases for these years.

Table 5

Results of Simulation of Withdrawal System with Two Ports at El 1071.4,* a Single Port at El 1062.0, a Single Port at El 1052.0, and All Ports of the Existing System**

Year	Normal Pool Elevation ft NGVD	Scenario	Objective Function Value	Number of Days of Band Violation	Maximum Band Violation °C	Average Difference from Objective °C
1967	1085	NA†	135	4	6.72	-0.55
1958	1085	NA	712	46	7.88	-1.51
1966	1085	2	163	14	4.13	-0.88
1964	1085	3	16	1	3.90	-0.21
1967	1080	NA	103	4	5.82	-0.36
1958	1080	NA	459	27	7.60	-1.20
1966	1080	2	105	10	3.80	-0.59
1964	1080	3	19	1	4.29	-0.19
1967	1075	NA	80	-4	4.77	-0.36
1958	1075	NA	447	28	7.58	-1.07
1966	1075	2	89	8	3.83	-0.57
1964	1075	3	12	1	3.43	-0.18

* All port elevations are center-line elevations.
** Existing ports 5 ft by 5 ft; additional ports 6 ft by 7 ft.
† NA denotes not applicable. No water supply releases for these years.

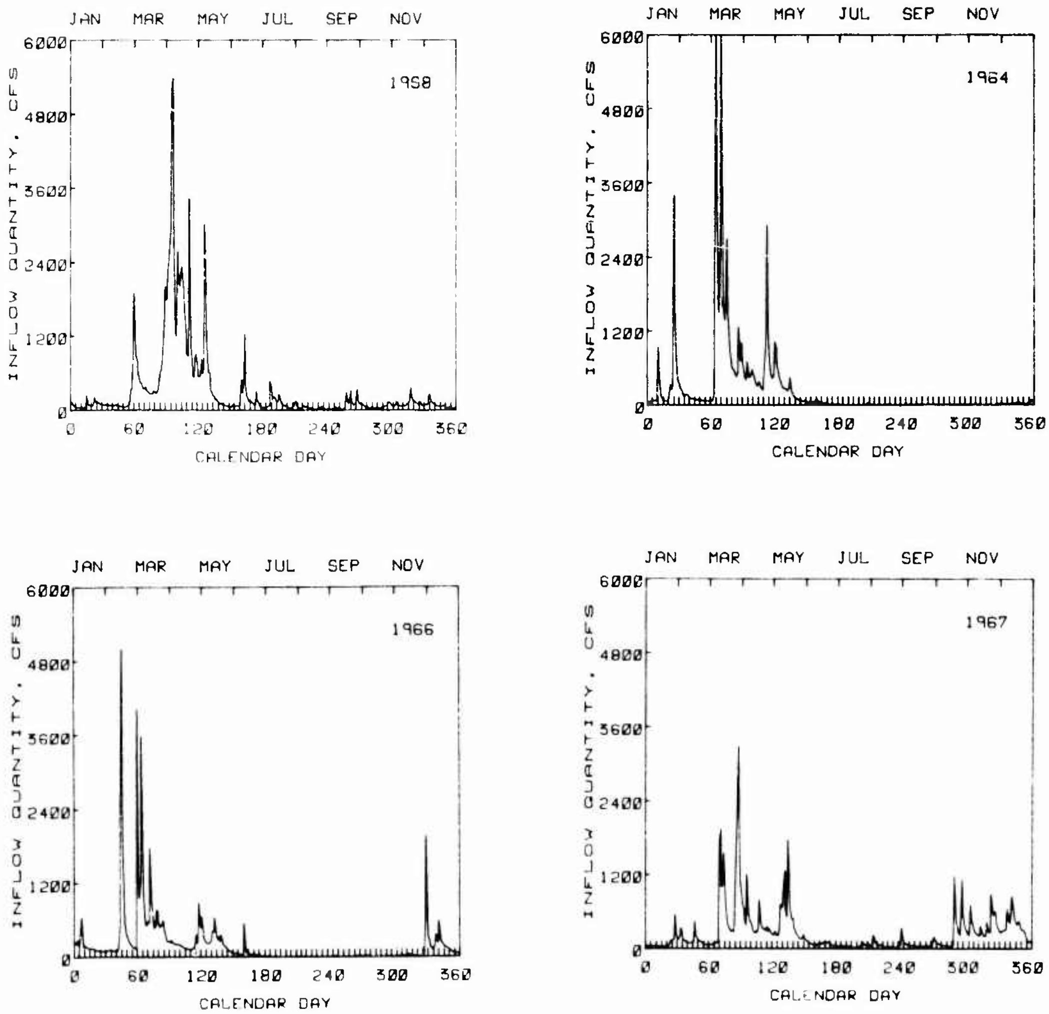

Plate 1A. Inflow quantity to Cowanesque Lake for 1958, 1964, 1966, and 1967. The maximum 1964 inflow value of 19,100 cfs (day 65) is off the scale above

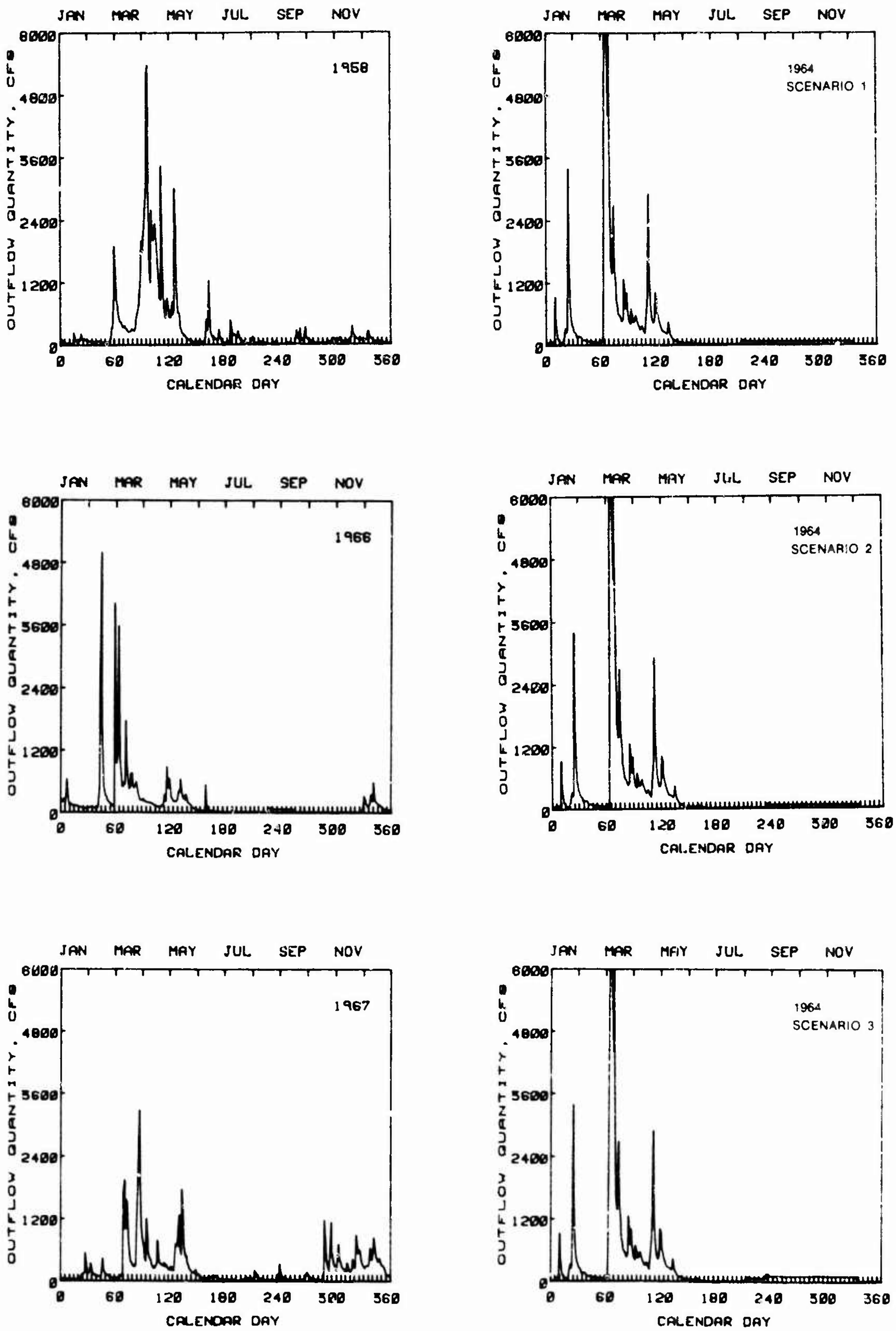

Plate 1B. Outflow quantity from Cowanesque Lake for 1958, 1966, 1967, and three water supply scenarios of 1964. A maximum outflow value of 6,000 cfs was simulated for each of the 1964 scenarios

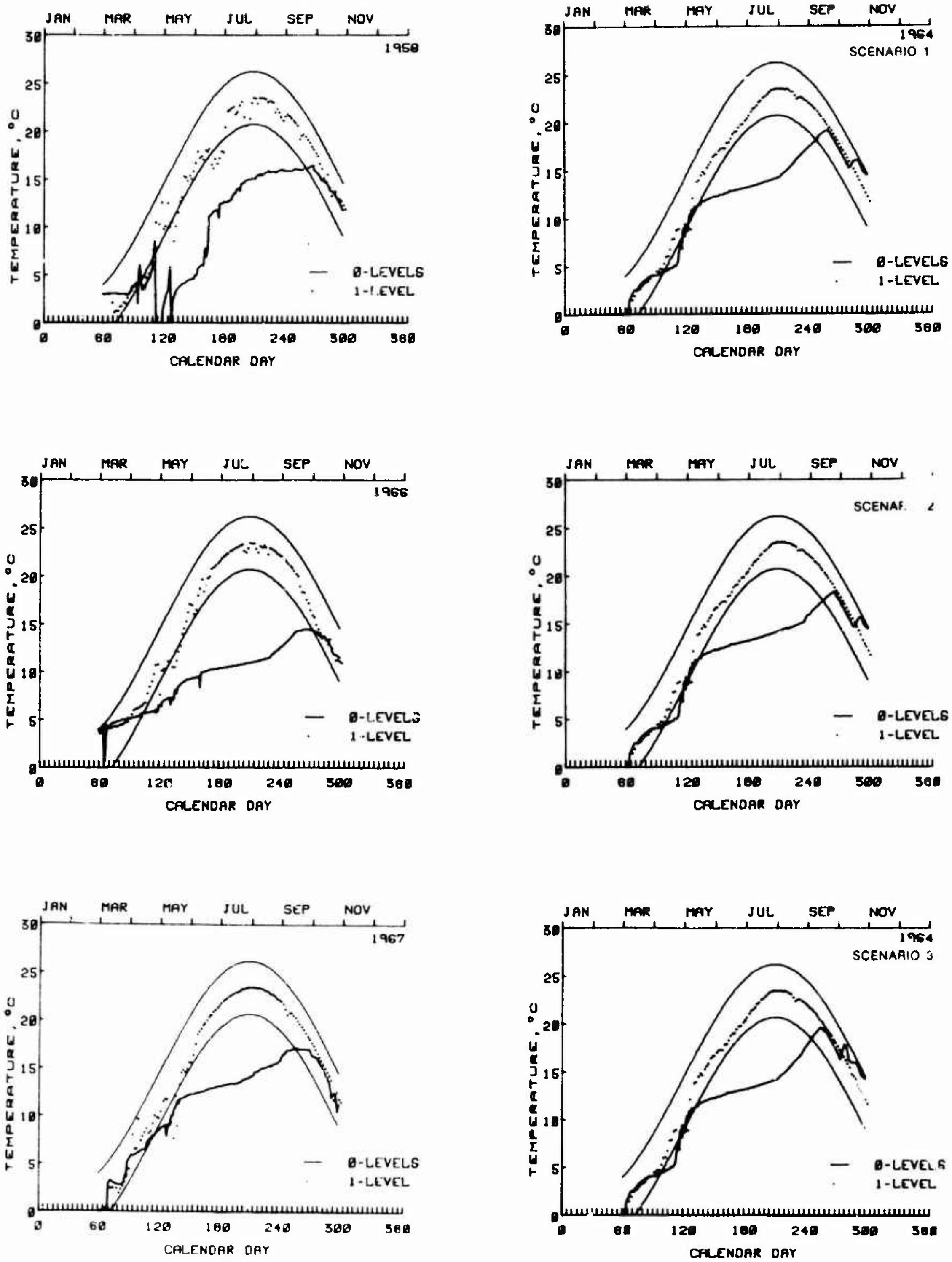

Plate 2A. Daily release temperatures for the existing system (0-levels) and existing system plus one additional level of small ports (1-level), pool el 1085.0

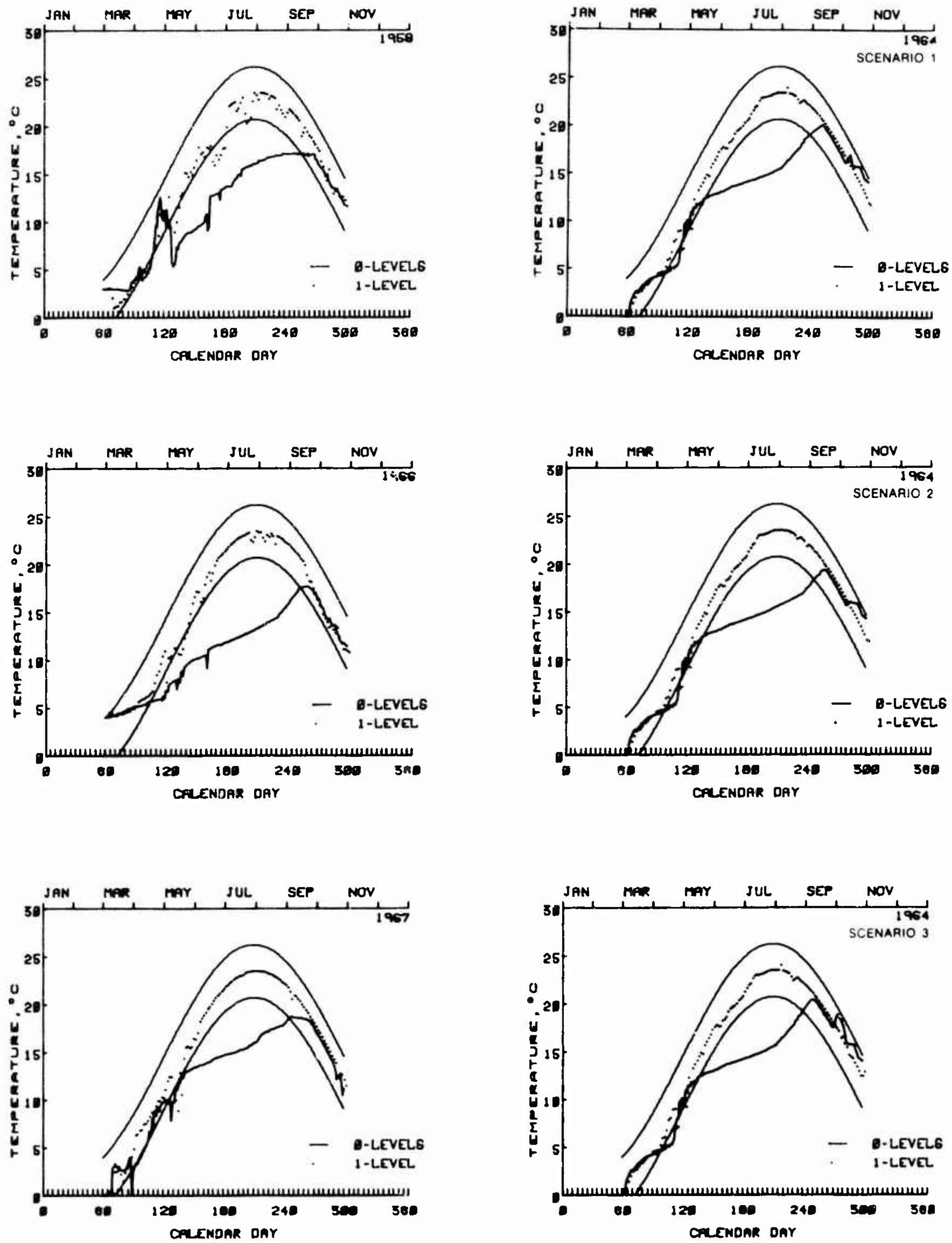

Plate 2B. Daily release temperatures for the existing system (0-levels) and existing system plus one additional level of small ports (1-level), pool el 1080.0

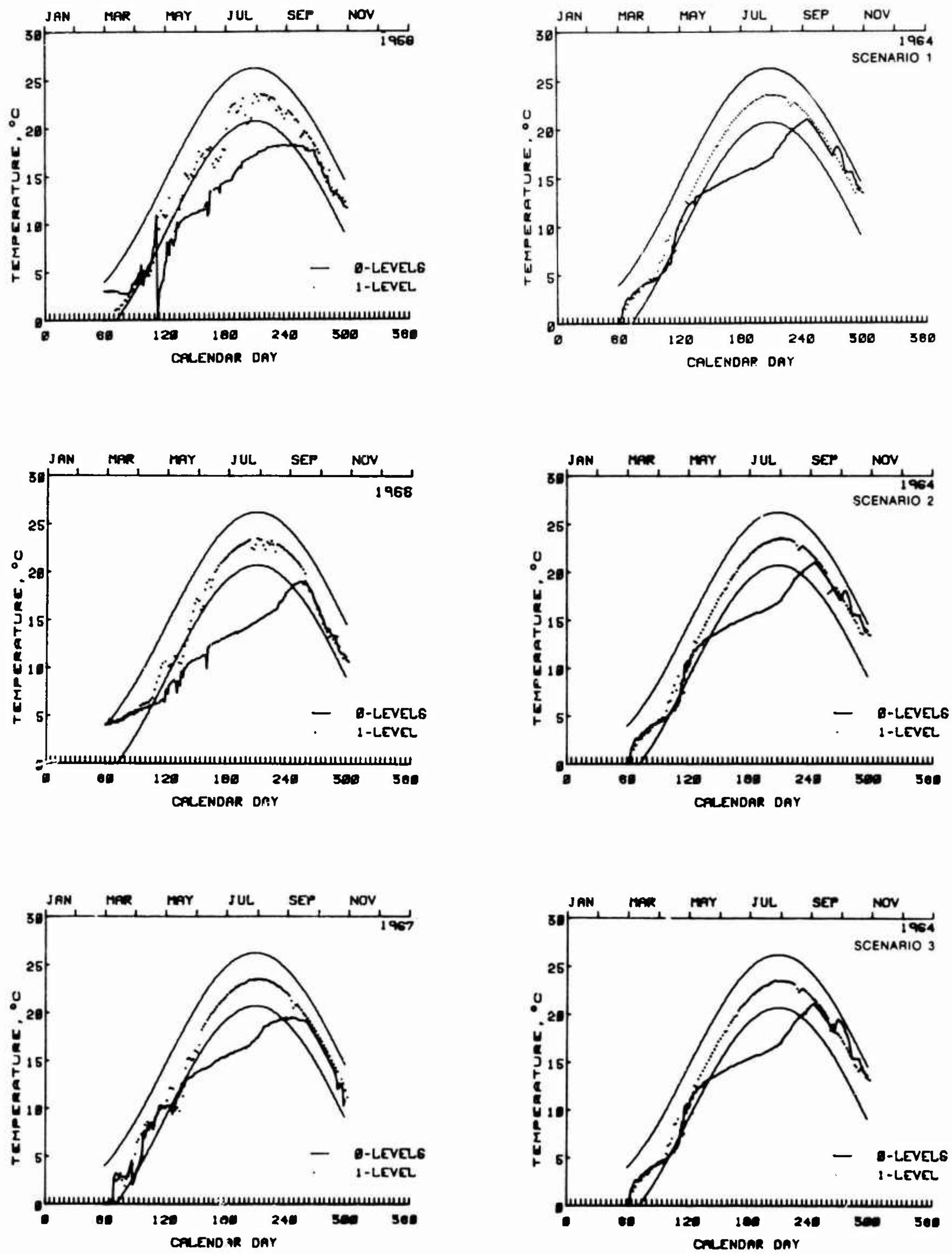

Plate 2C. Daily release temperatures for the existing system (0-levels) and existing system plus one additional level of small ports (1-level), pool el 1075.0

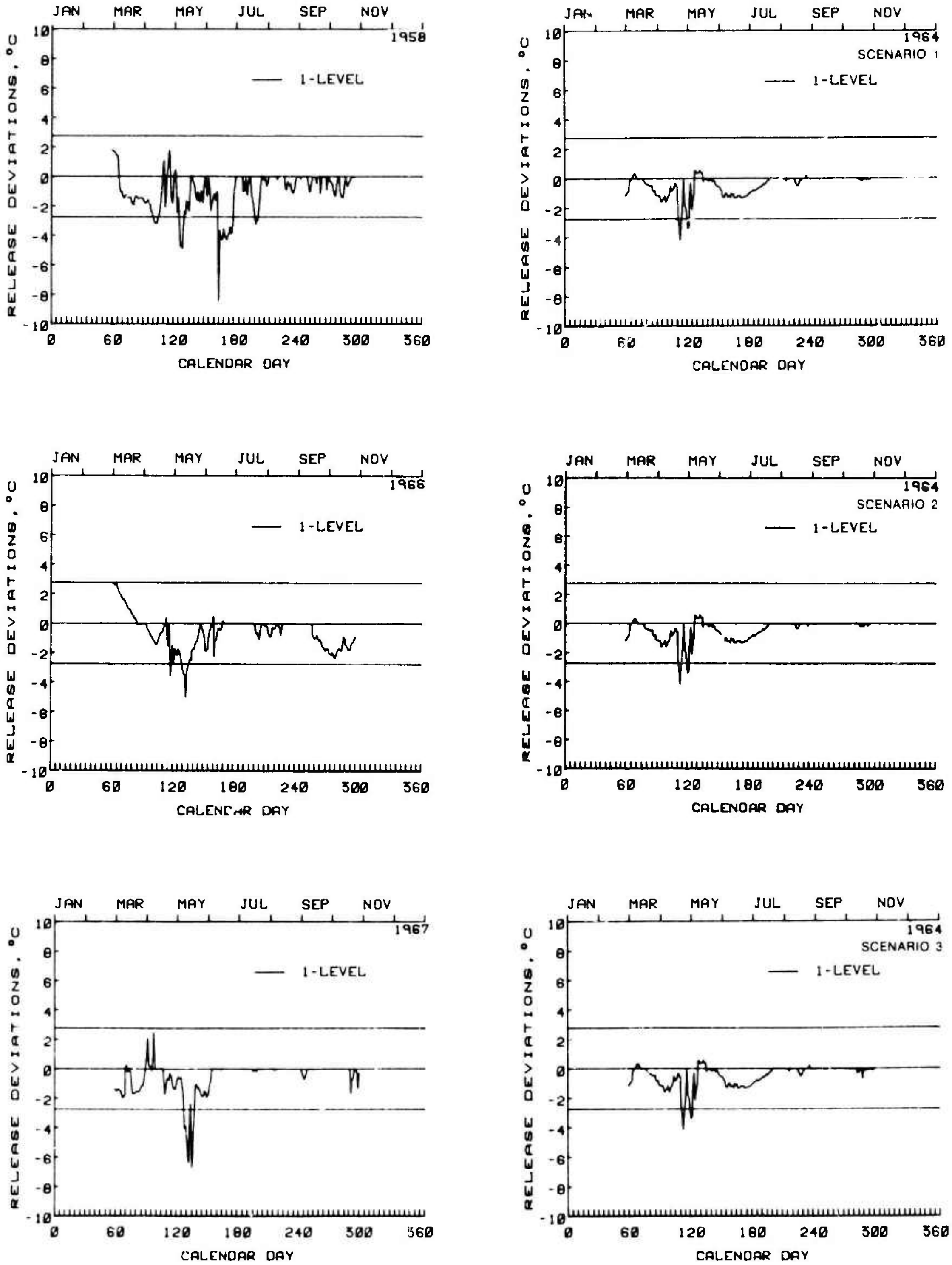

Plate 3A. Deviation of predicted daily release temperature from objective temperature with one additional level of small ports, pool el 1085.0

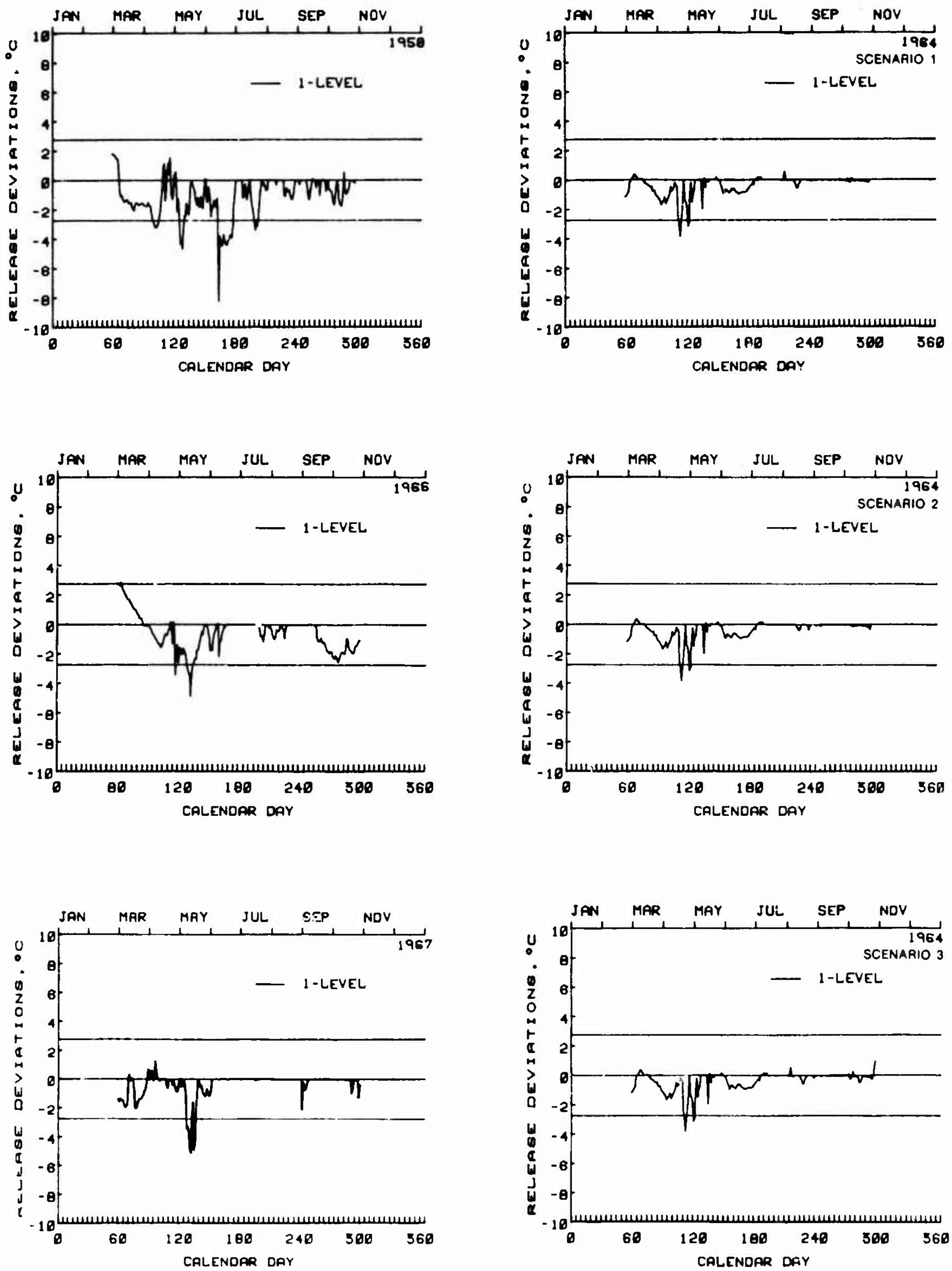

Plate 3B. Deviation of predicted daily release temperature from objective temperature with one additional level of small ports, pool el 1080.0

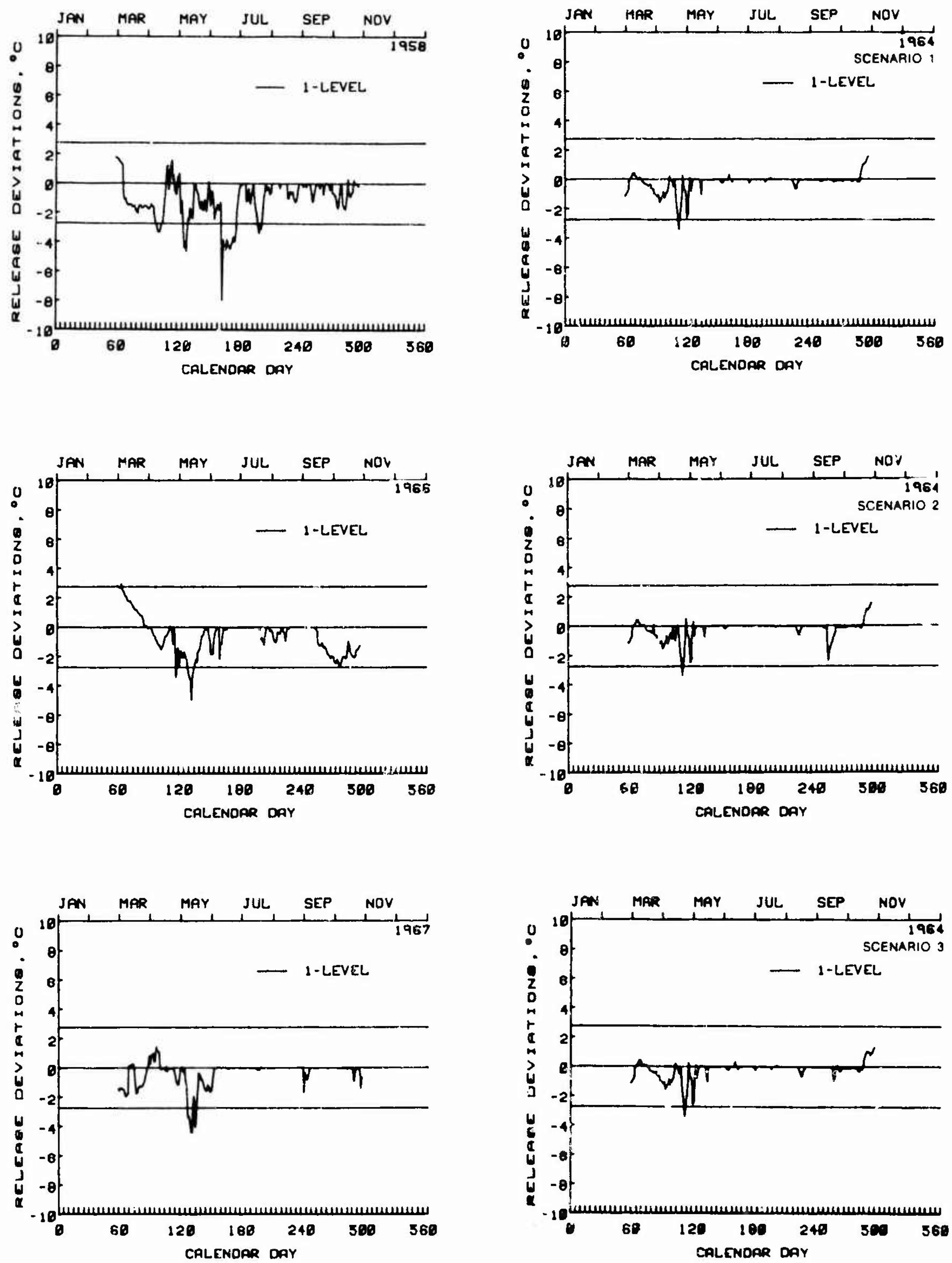

Plate 3C. Deviation of predicted daily release temperature from objective temperature with one additional level of small ports, pool el 1075.0

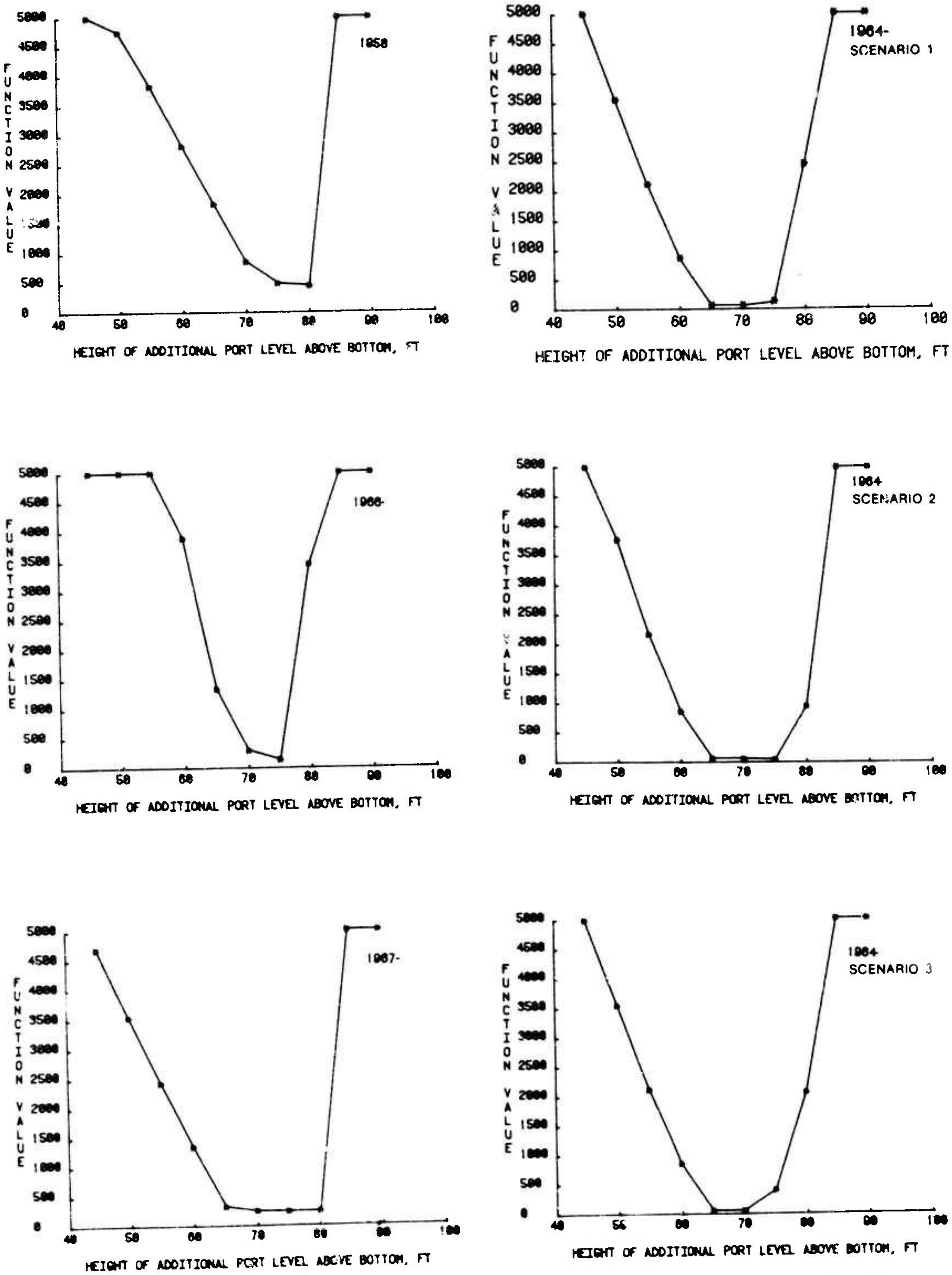

Plate 4A. Objective function value as a function of port height above lake bottom (el 1000.0) with one additional level of small ports, pool el 1085.0

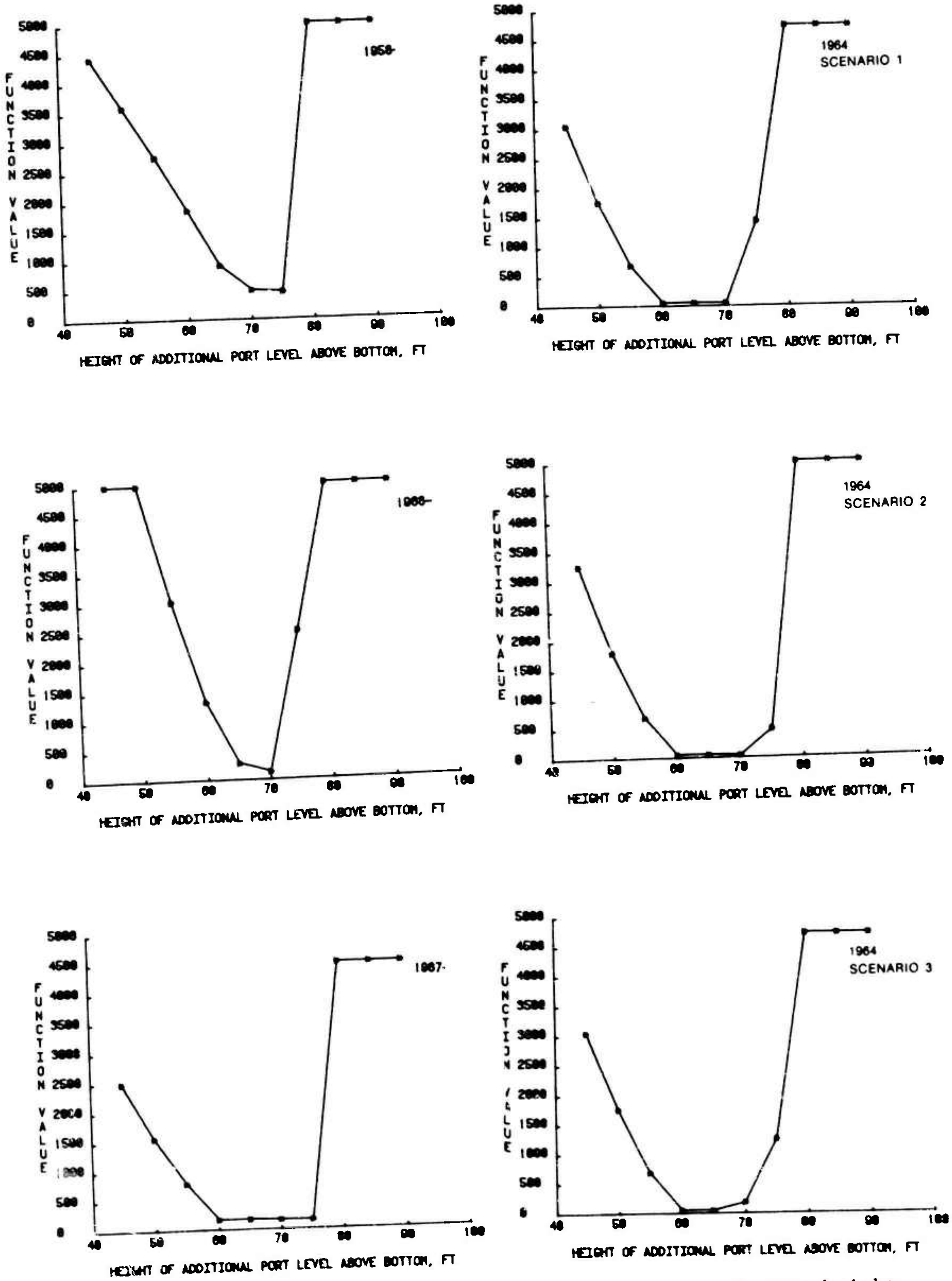

Plate 4B. Objective function value as a function of port height above lake bottom (el 1000.0) with one additional level of small ports, pool el 1080.0

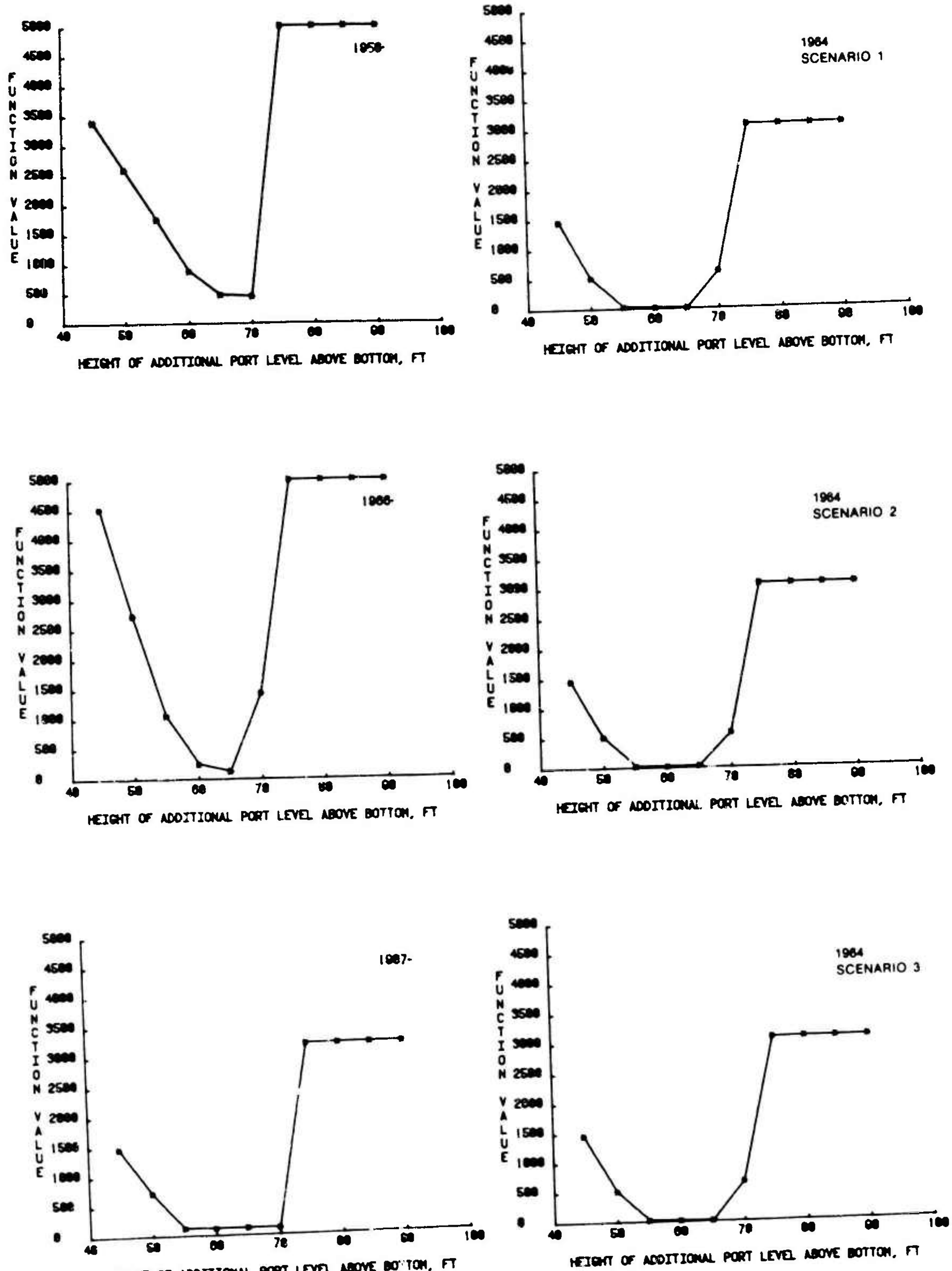

Plate 4C. Objective function value as a function of port height above lake bottom (el 1000.0) with one additional level of small ports, pool el 1075.0

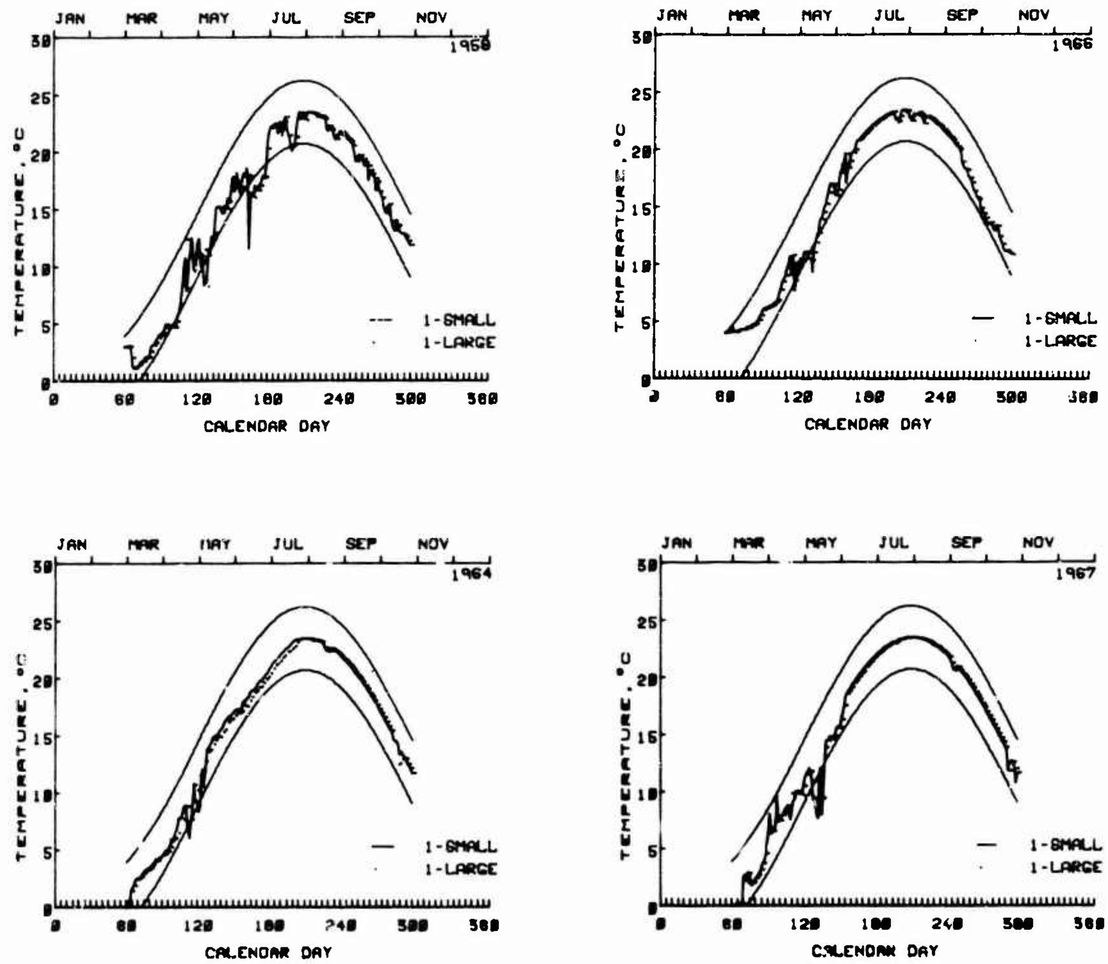

Plate 5A. Release temperatures for one additional level of ports of 5- by 5-ft (small) ports and one additional level of ports of 6- by 7-ft (large) ports, pool el 1085.0

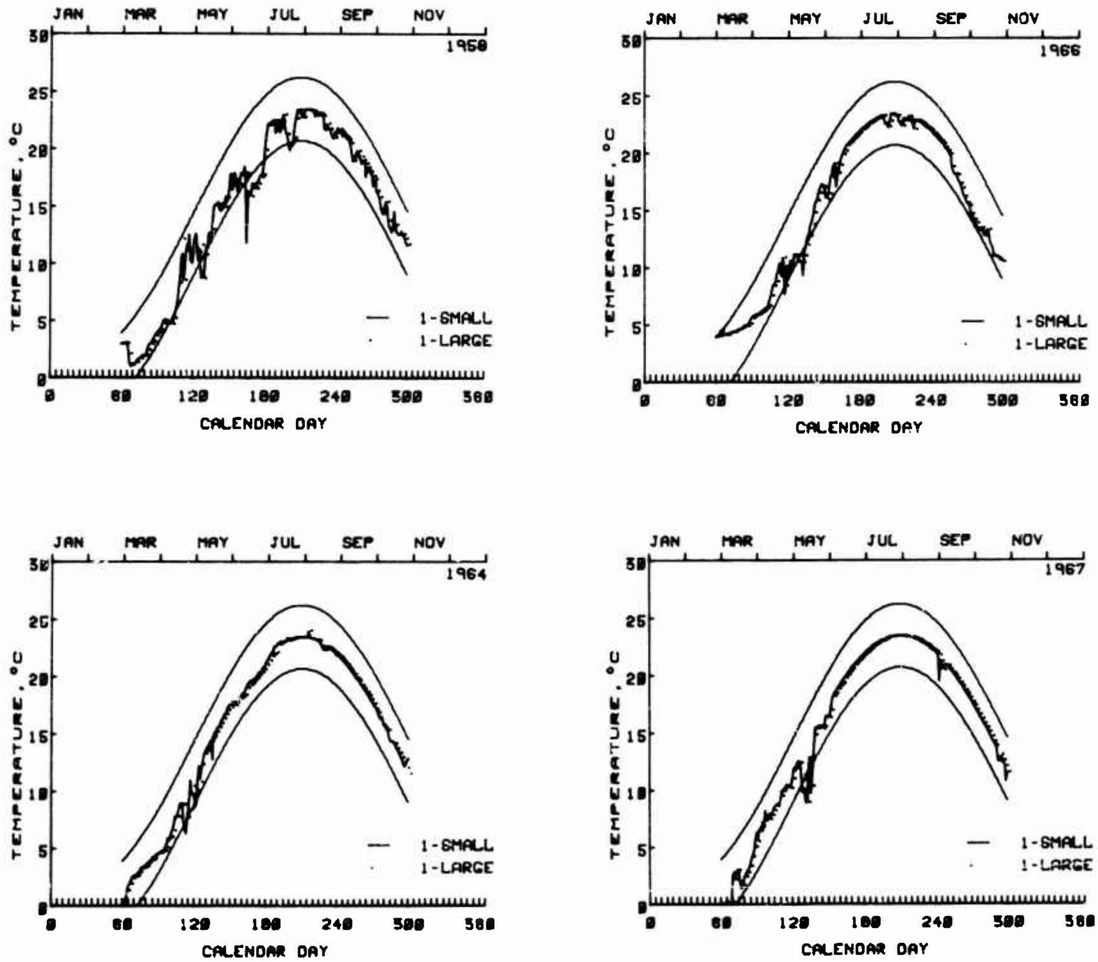

Plate 5B. Release temperatures for one additional level of ports by 5- by 5-ft (small) ports and one additional level of ports of 6- by 7-ft (large) ports, pool el 1080.0

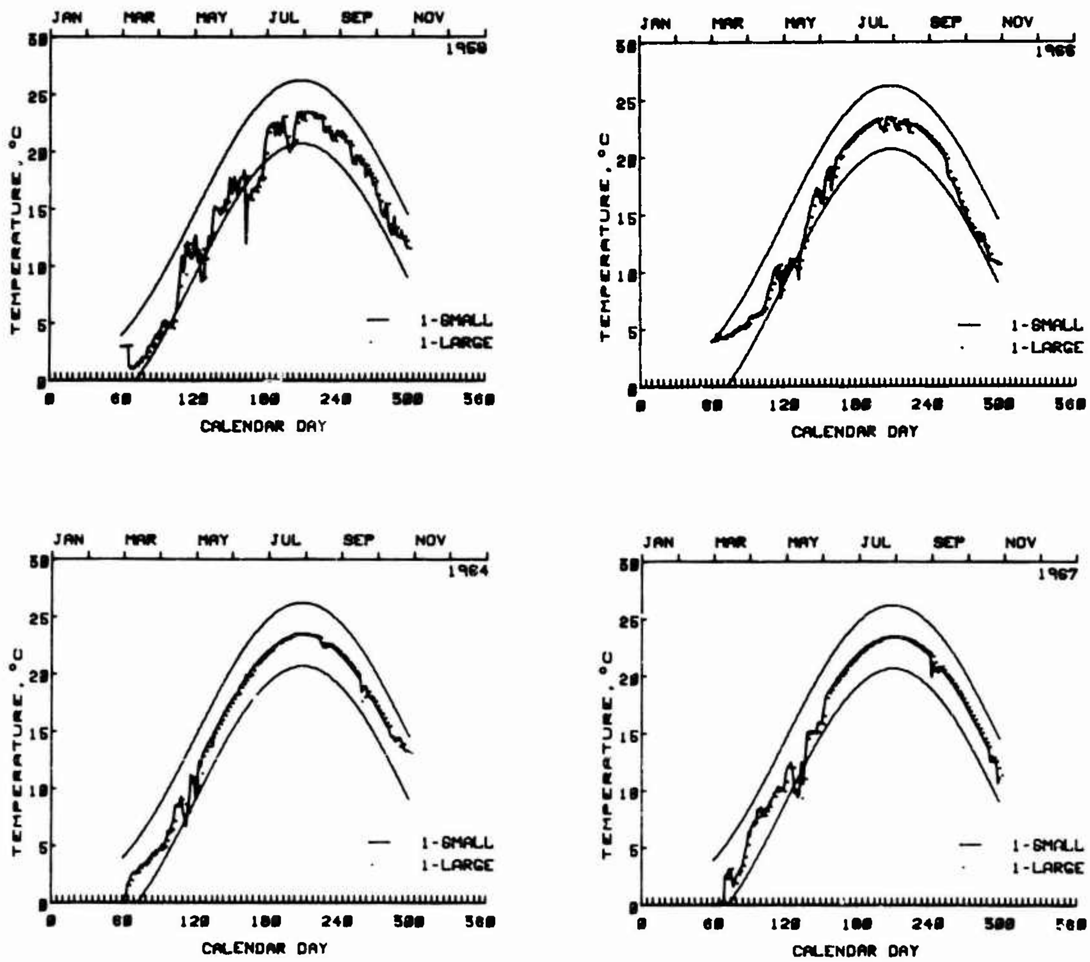

Plate 5C. Release temperatures for one additional level of ports of 5- by 5-ft (small) ports and one additional level of ports of 6- by 7-ft (large) ports, pool el 1075.0

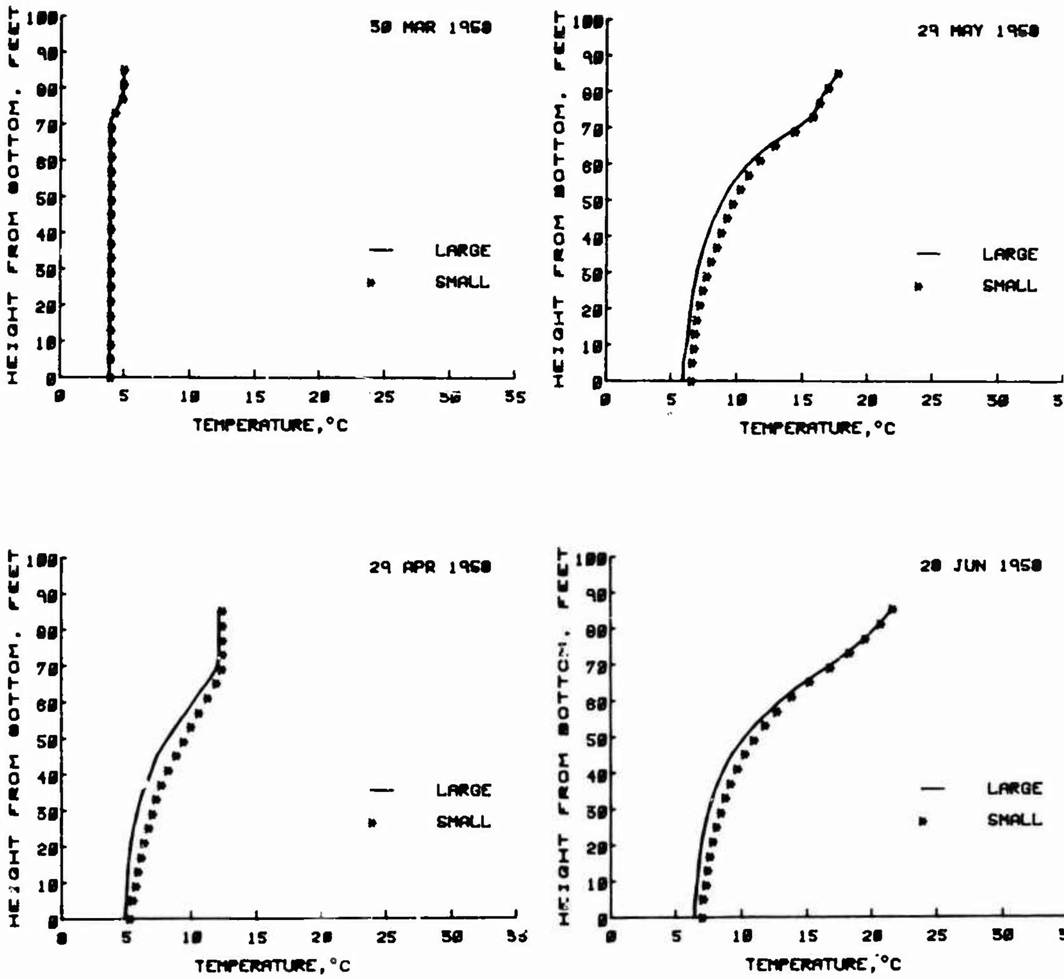

Plate 6A. Temperature profiles, pool el 1085.0, Mar-Jun 1958, with one additional level of large and small ports

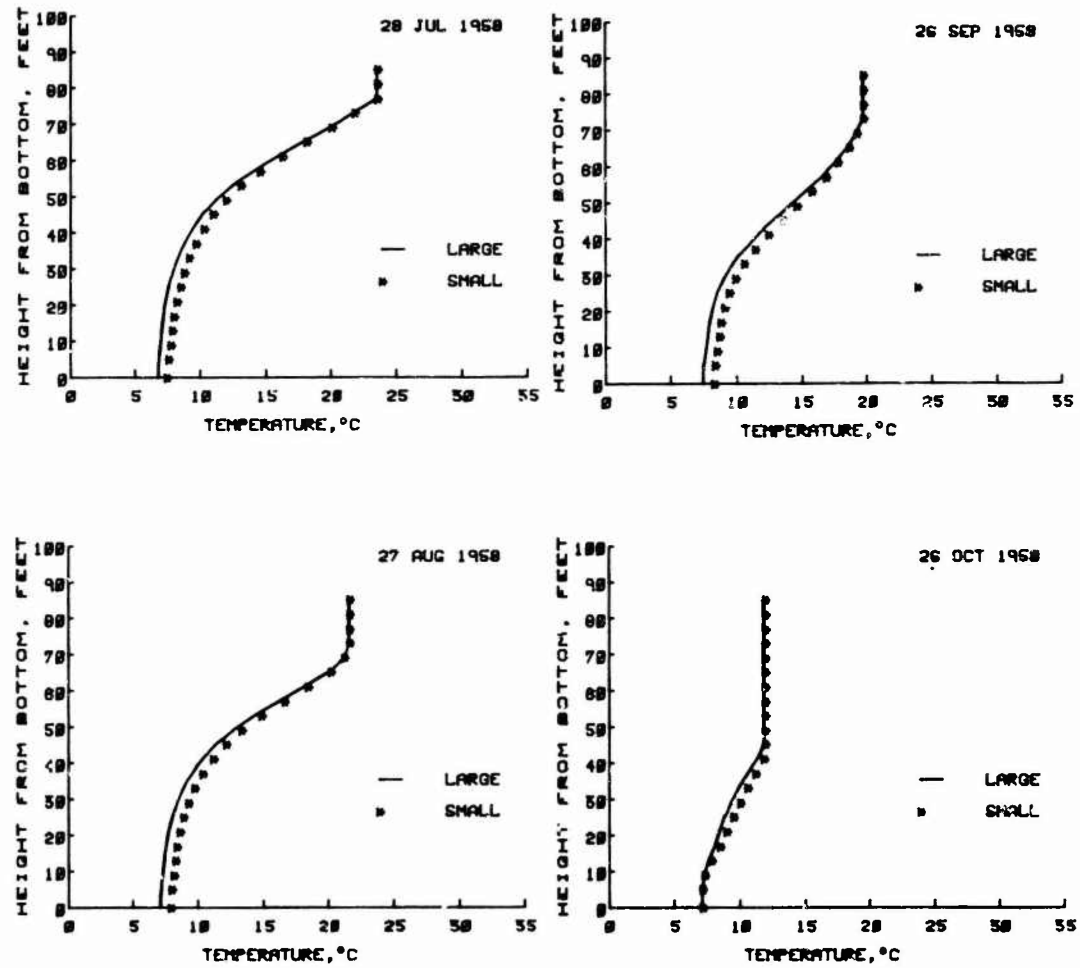

Plate 6B. Temperature profiles, pool el 1085.0, Jul-Oct 1958, with one additional level of large and small ports

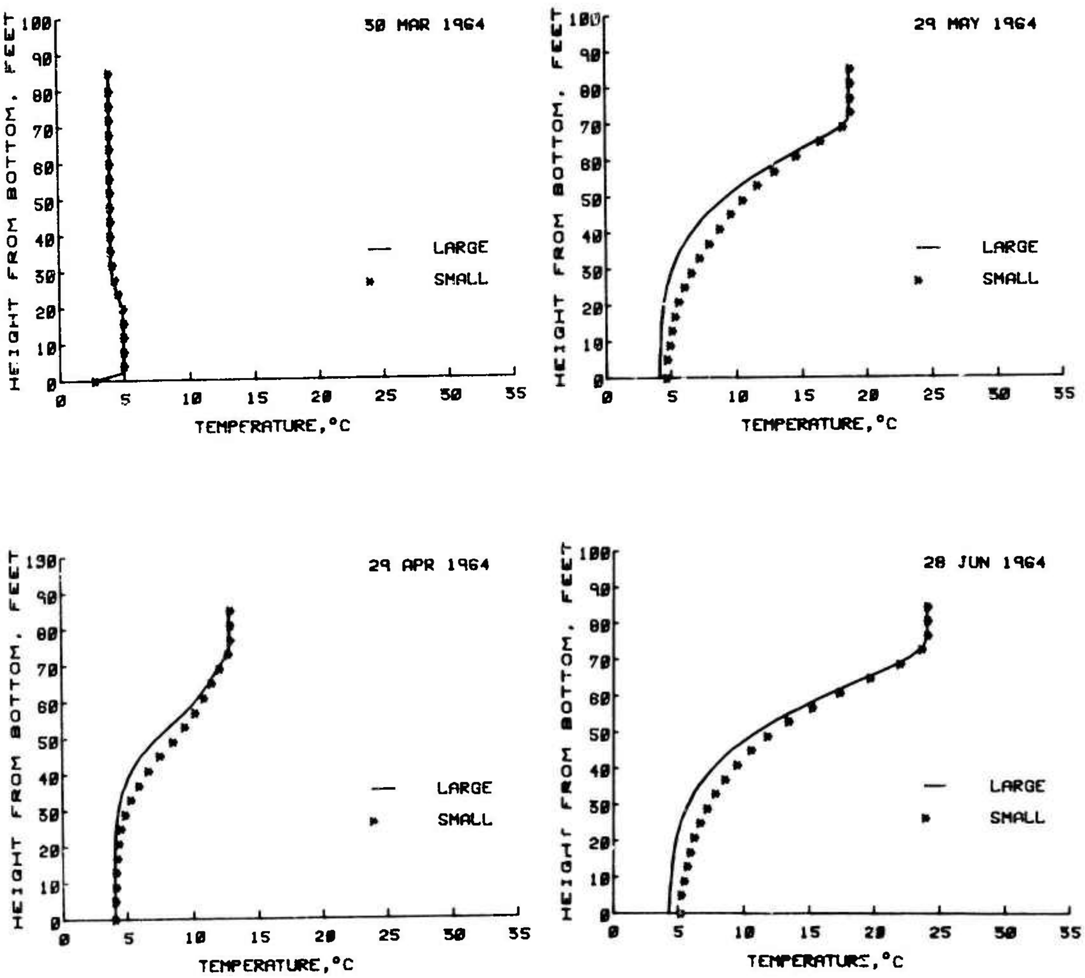

Plate 6C. Temperature profiles, pool el 1085.0, Mar-Jun 1964, with one additional level of large and small ports

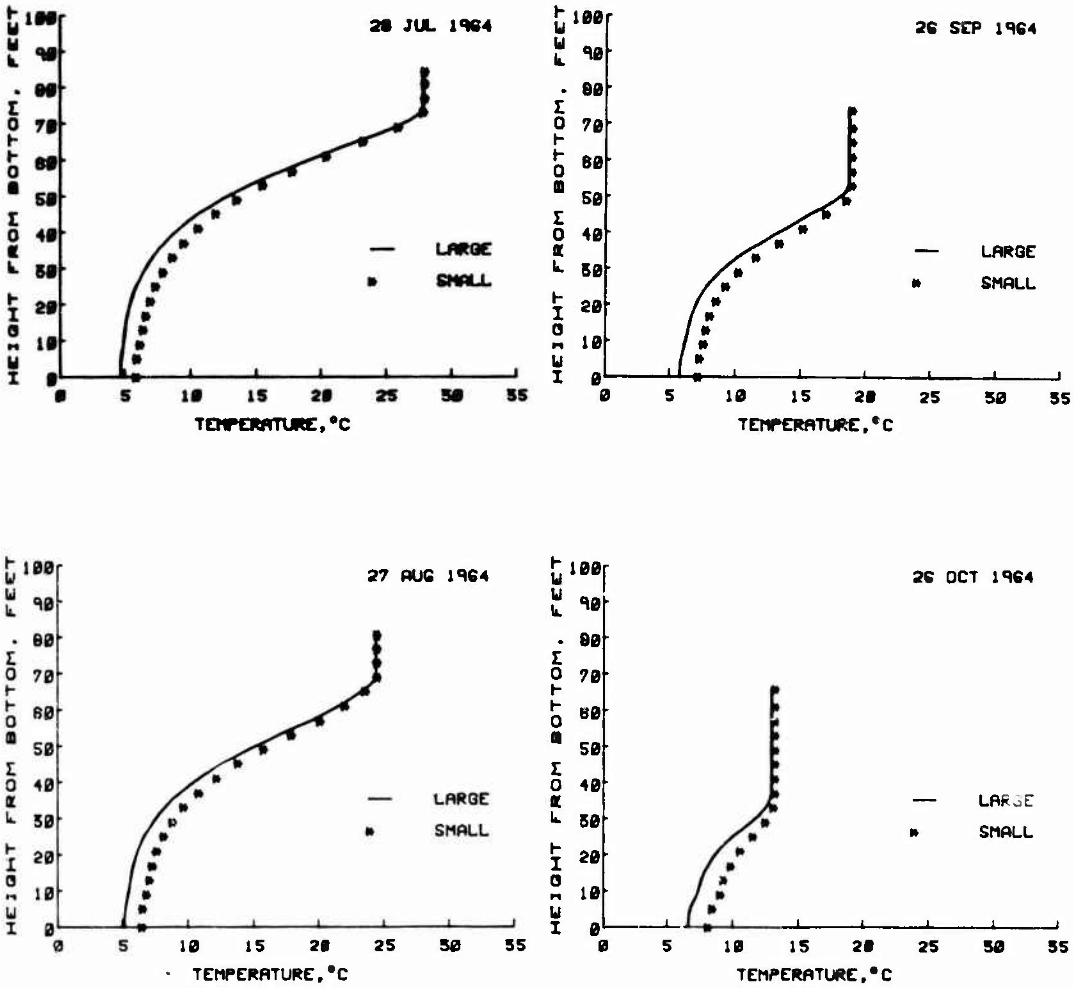

Plate 6D. Temperature profiles, pool el 1085.0, Jul-Oct 1964, with one additional level of large and small ports

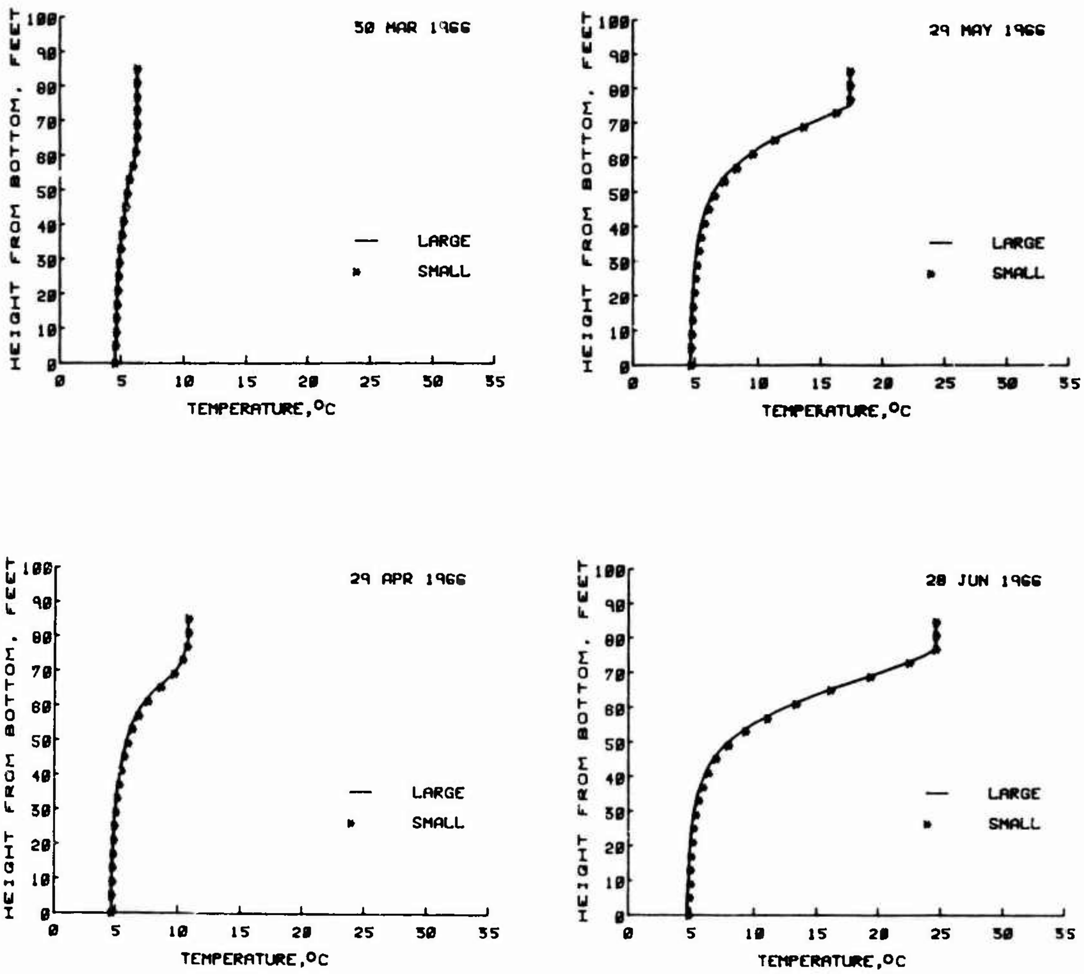

Plate 6E. Temperature profiles, pool el 1085.0, Mar-Jun 1966, with one additional level of large and small ports

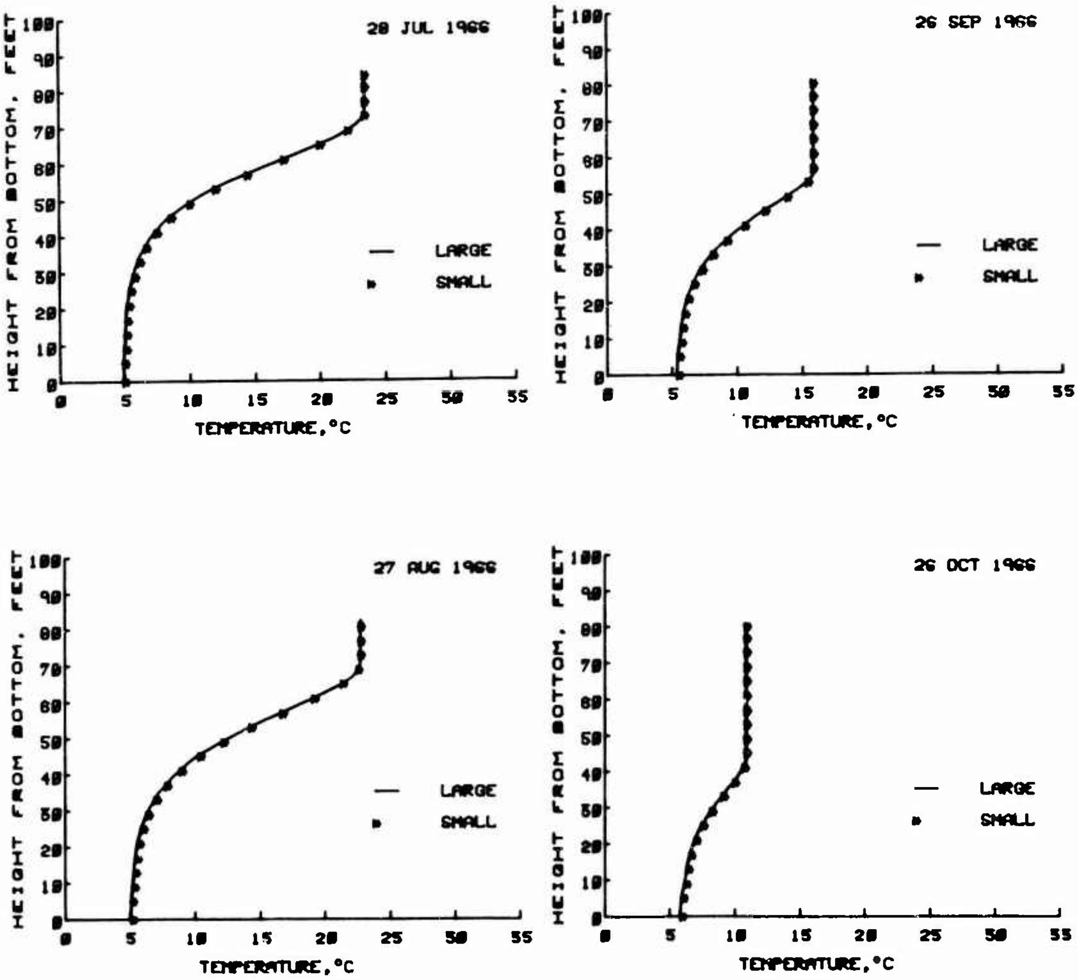

Plate 6F. Temperature profiles, pool el 1085.0, Jul-Oct 1966, with one additional level of large and small ports

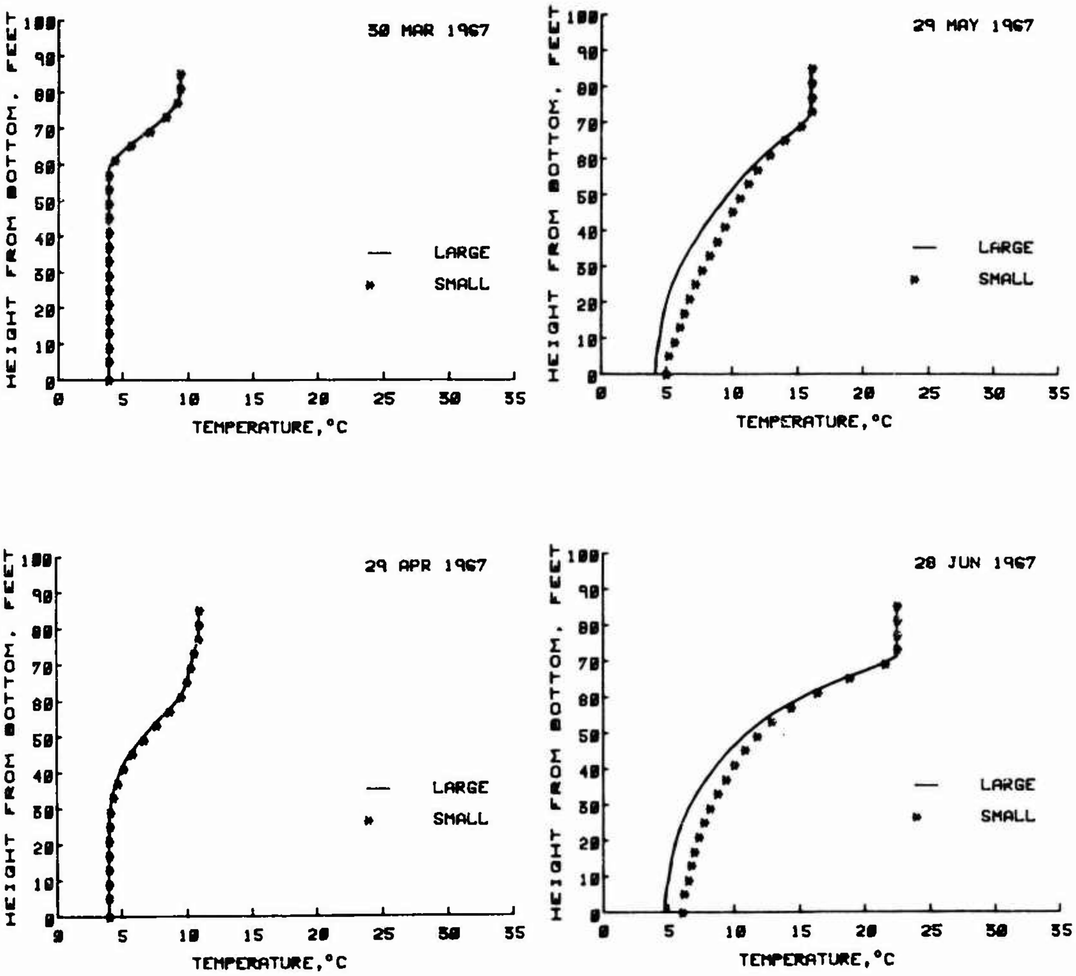

Plate 6G. Temperature profiles, pool el 1085.0, Mar-Jun 1967, with one additional level of large and small ports

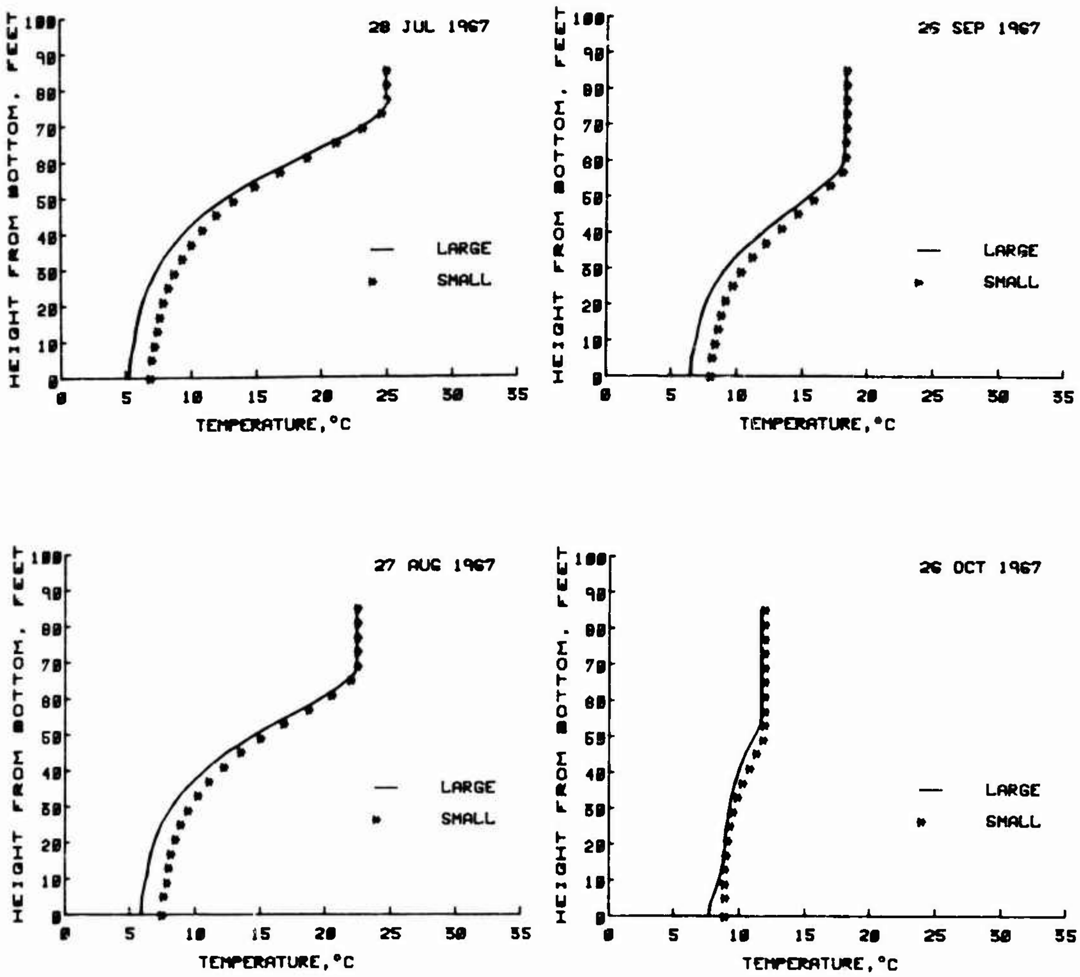

Plate 6H. Temperature profiles, pool el 1085.0, Jul-Oct 1967, with one additional level of large and small ports

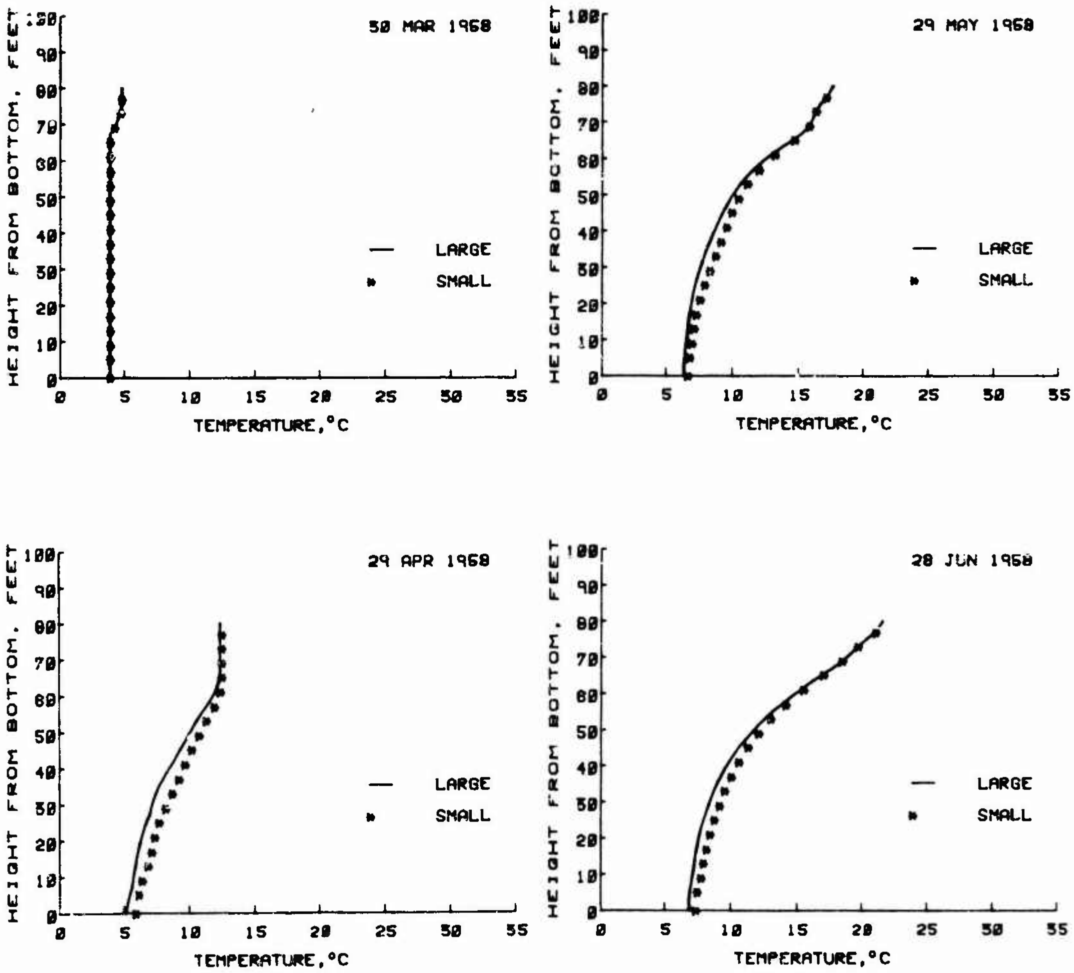

Plate 6I. Temperature profiles, pool el 1080.0, Mar-Jun 1958, with one additional level of large and small ports

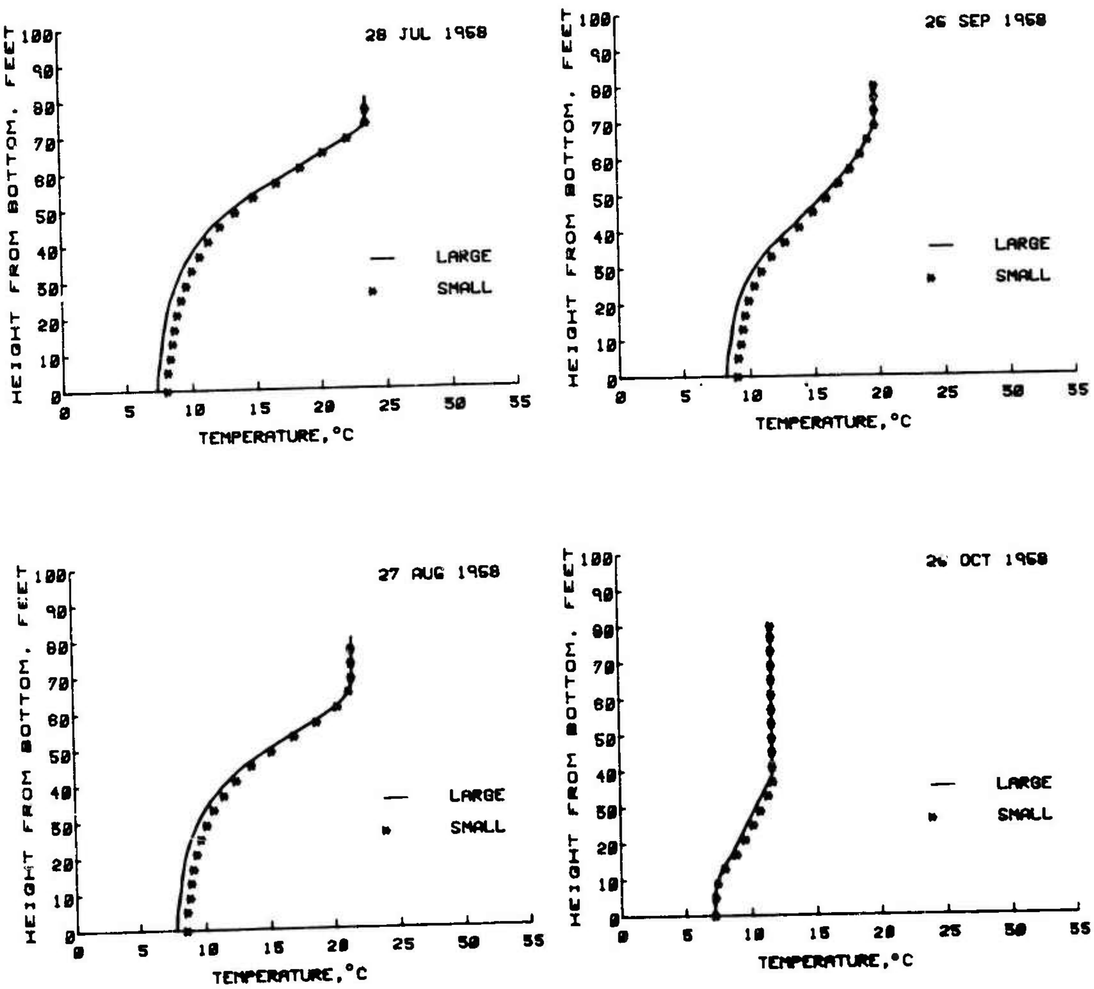

Plate 6J. Temperature profiles, pool el 1080.0, Jul-Oct 1958, with one additional level of large and small ports

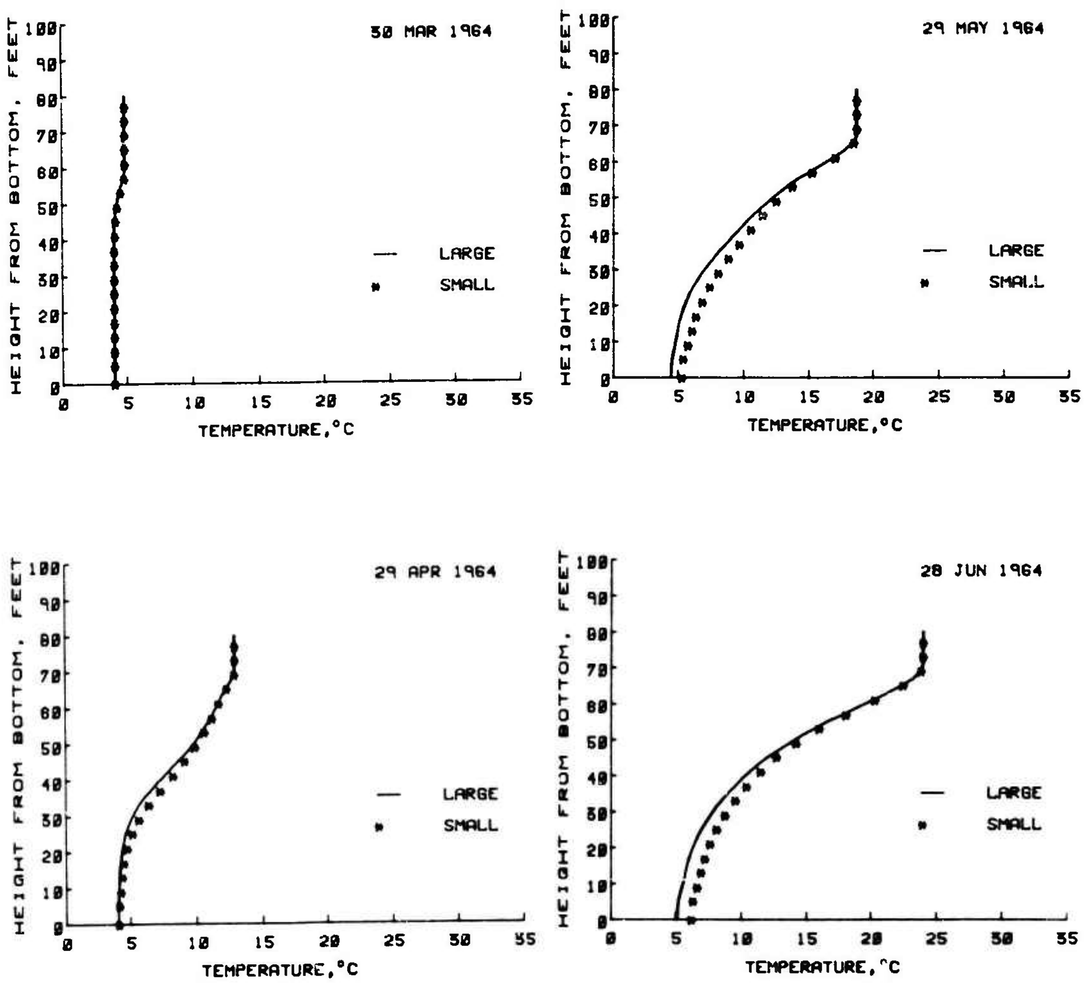

Plate 6K. Temperature profiles, pool el 1080.0, Mar-Jun 1964, with one additional level of large and small ports

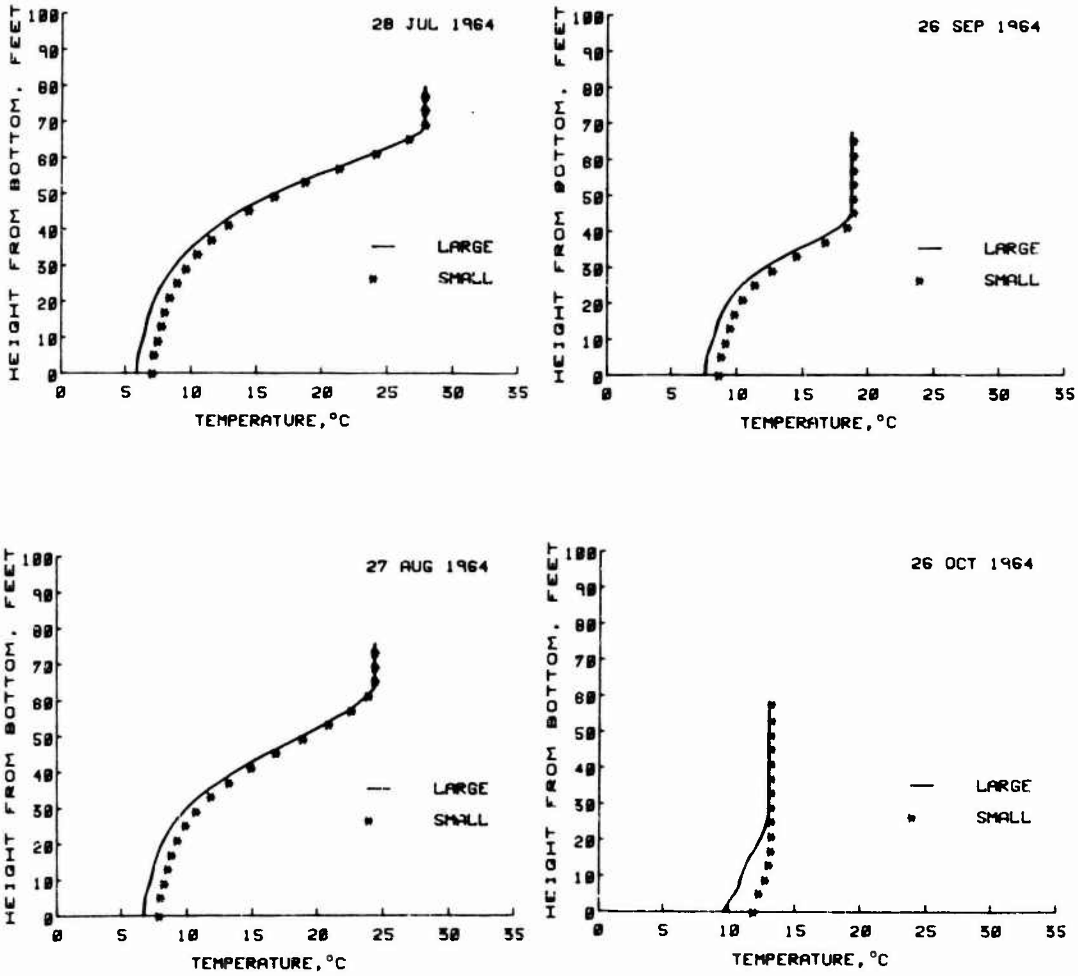

Plate 6L. Temperature profiles, pool el 1080.0, Jul-Oct 1964, with one additional level of large and small ports

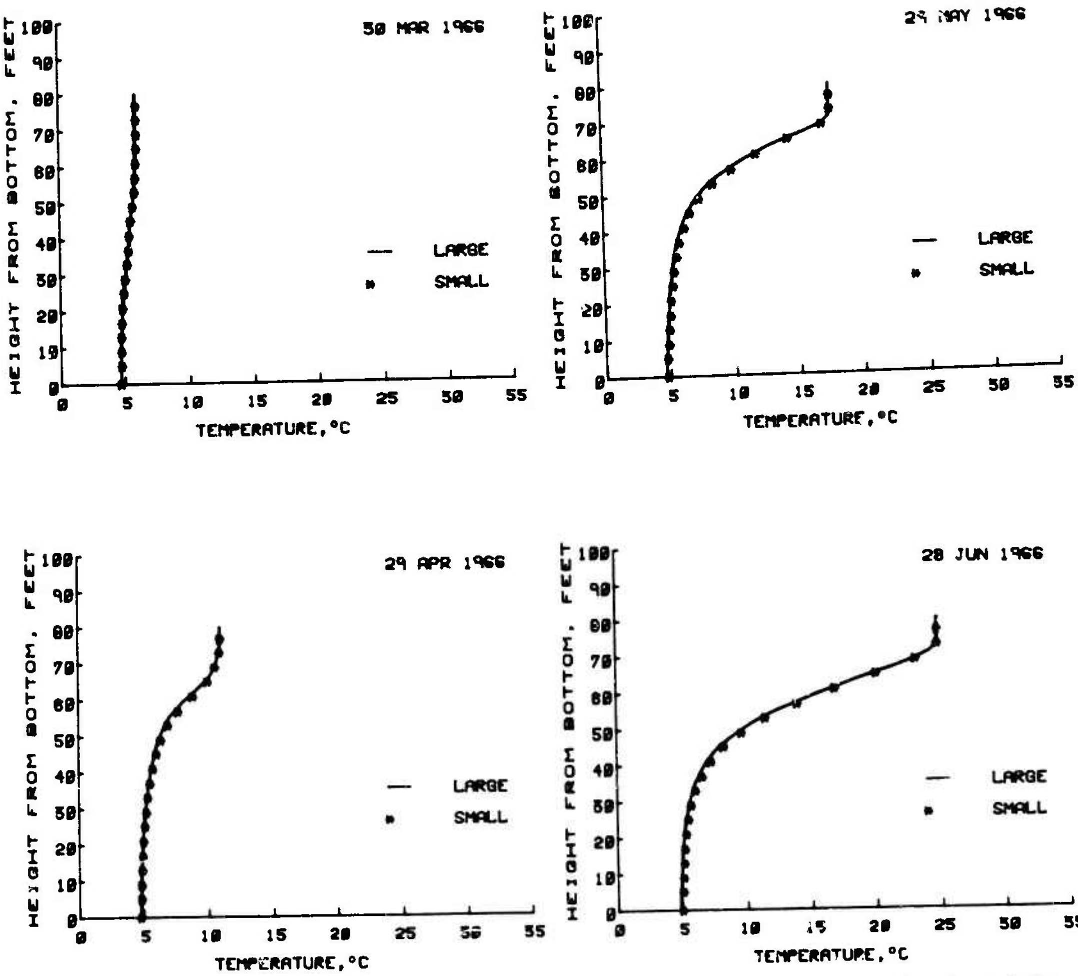

Plate 6M. Temperature profiles, pool el 1080.0, Mar-Jun 1966, with one additional level of large and small ports

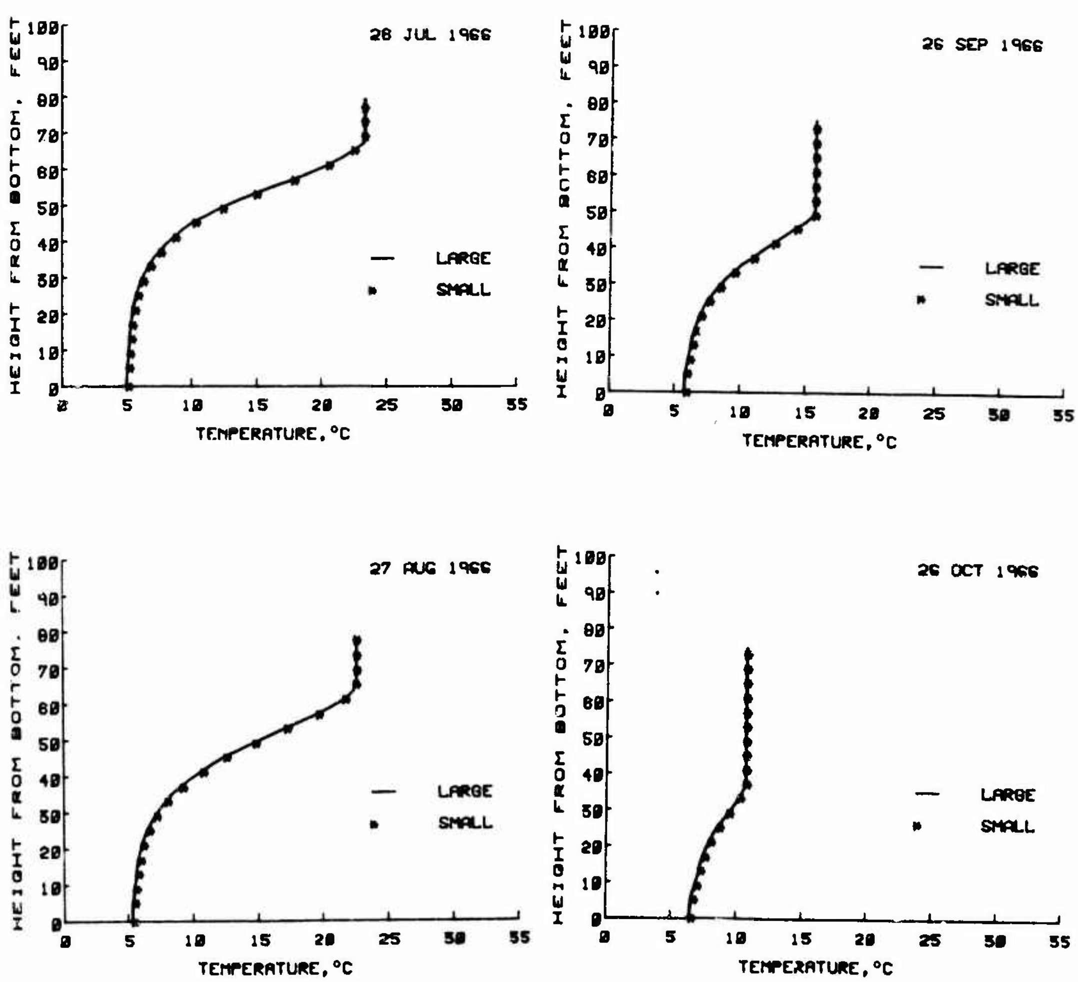

Plate 6N. Temperature profiles, pool el 1080.0, Jul-Oct 1966, with one additional level of large and small ports

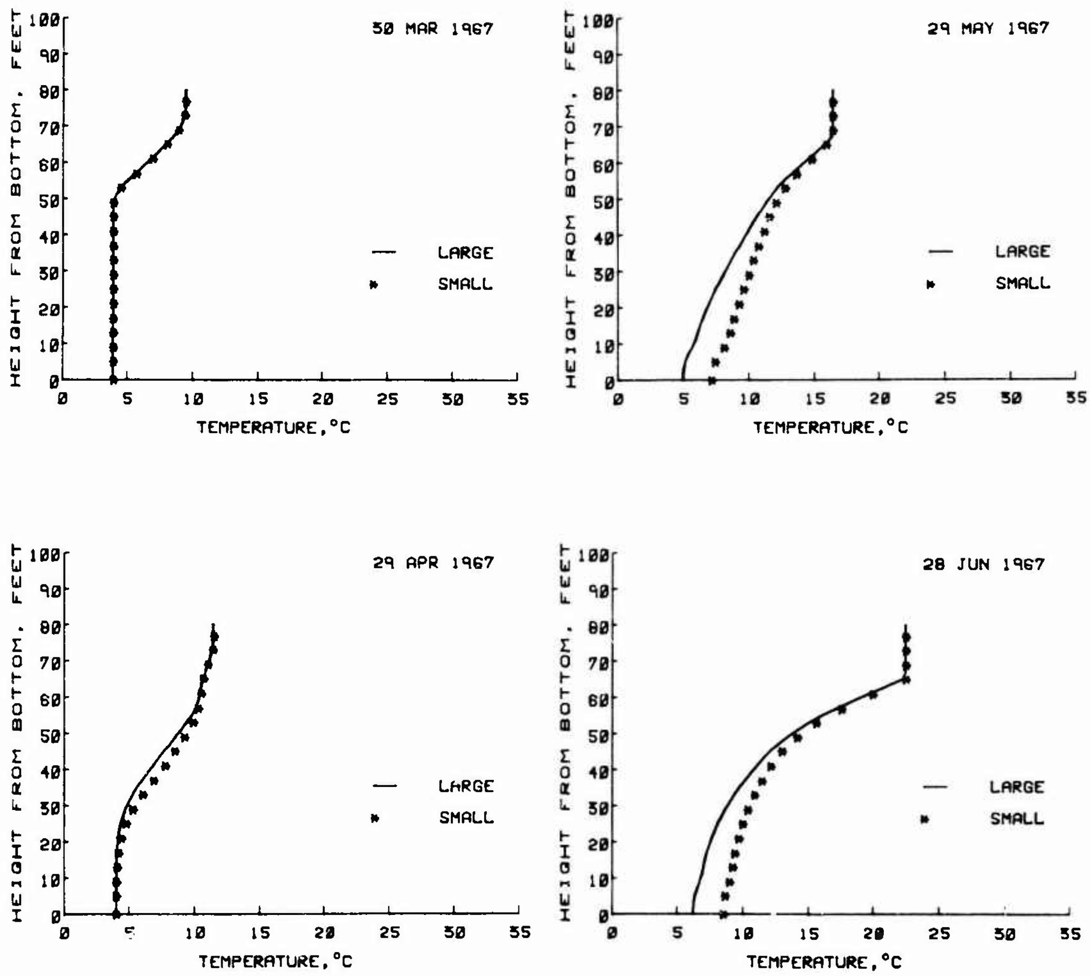

Plate 60. Temperature profiles, pool el 1080.0, Mar-Jun 1967, with one additional level of large and small ports

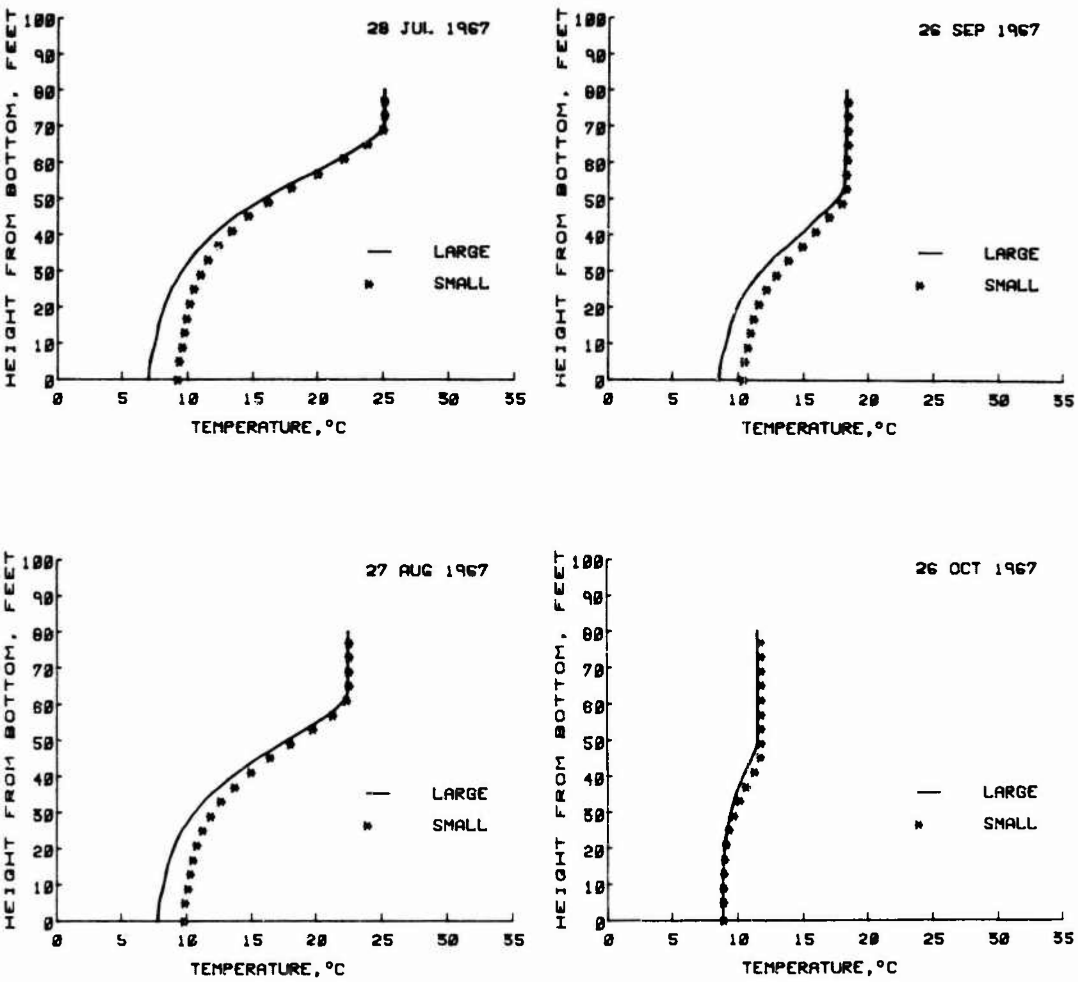

Plate 6P. Temperature profiles, pool el 1080.0, Jul-Oct 1967, with one additional level of large and small ports

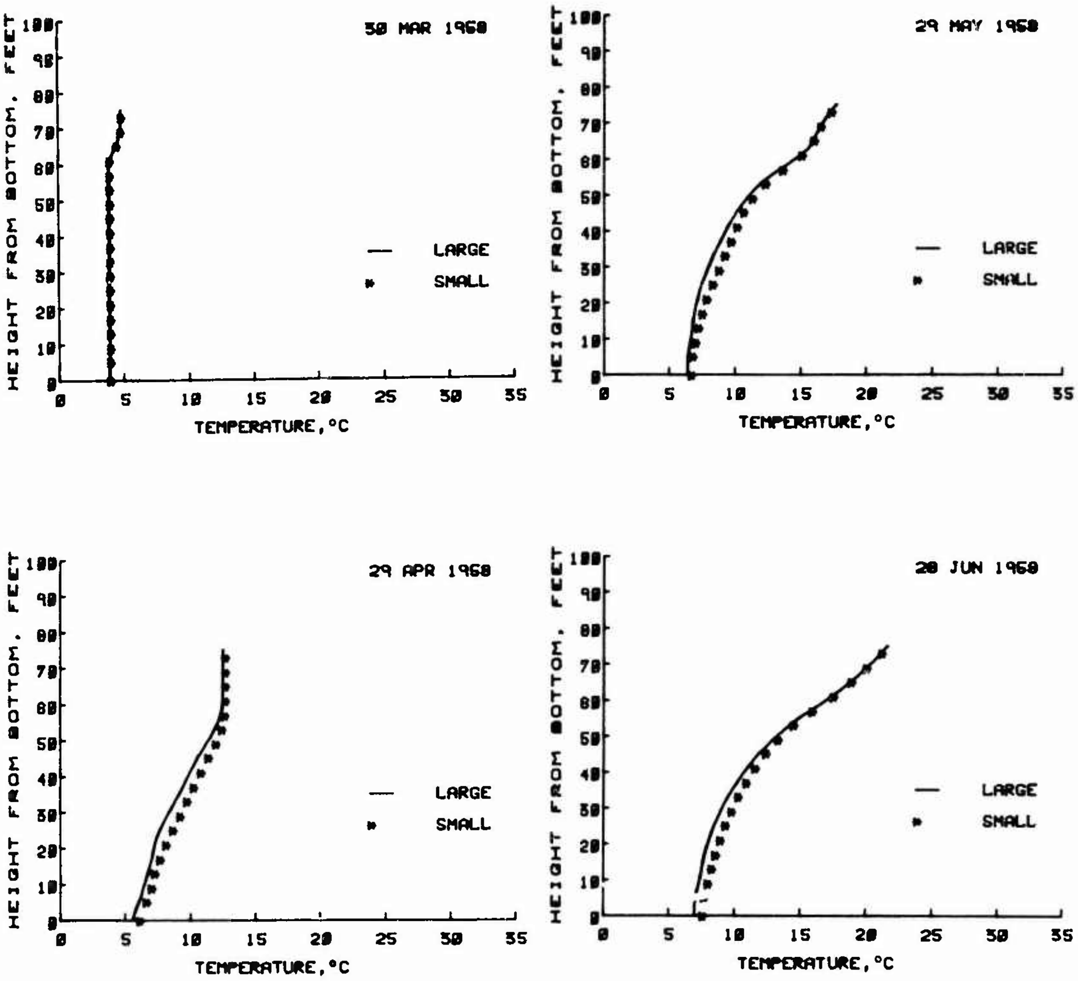

Plate 6Q. Temperature profiles, pool el 1075.0, Mar-Jun 1958, with one additional level of large and small ports

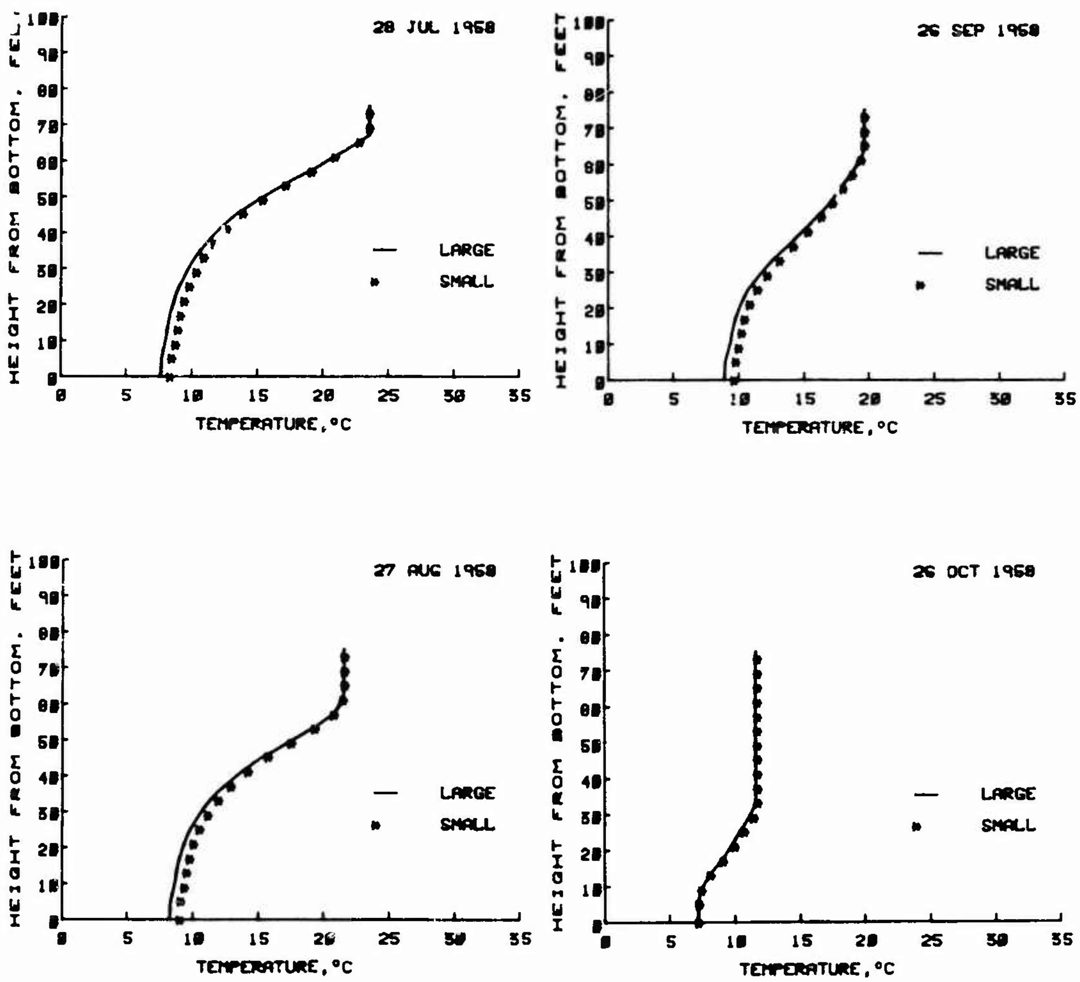

Plate 6R. Temperature profiles, pool el 1075.0, Jul-Oct 1958, with one additional level of large and small ports

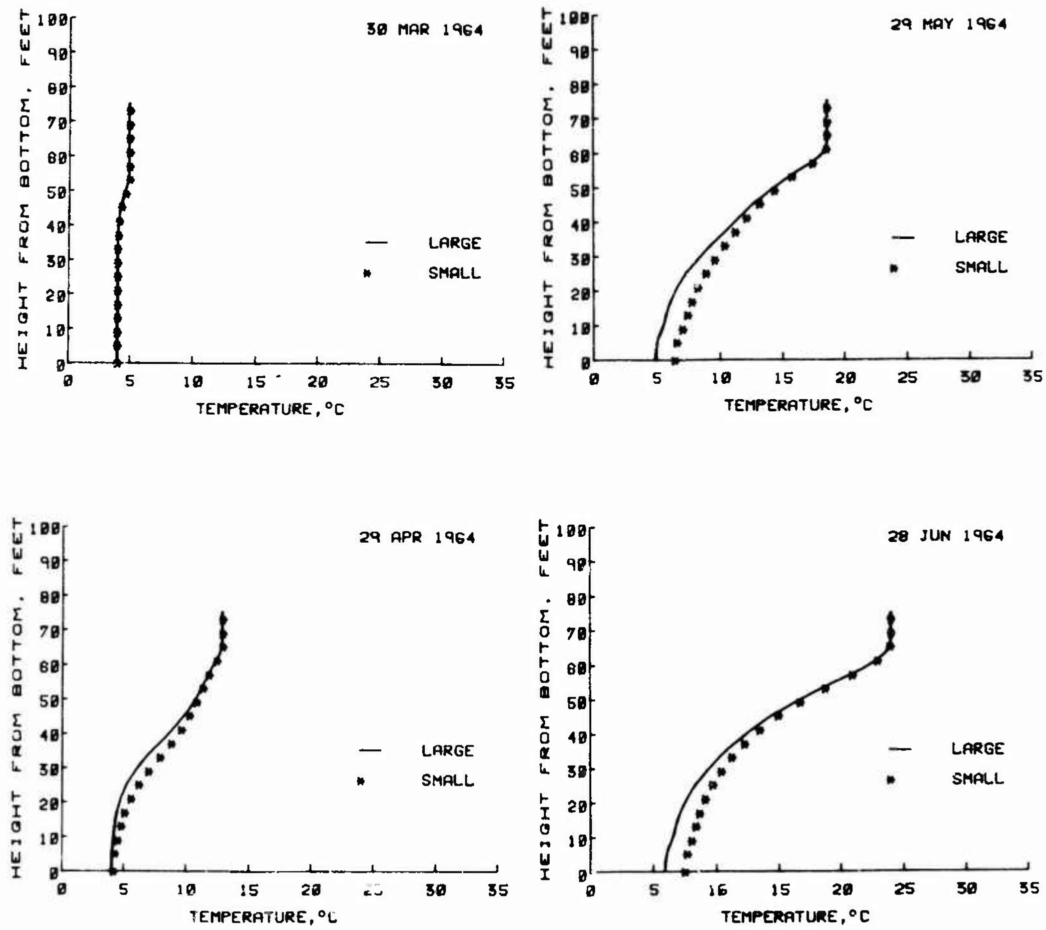

Plate 6S. Temperature profiles, pool el 1075.0, Mar-Jun 1964, with one additional level of large and small ports

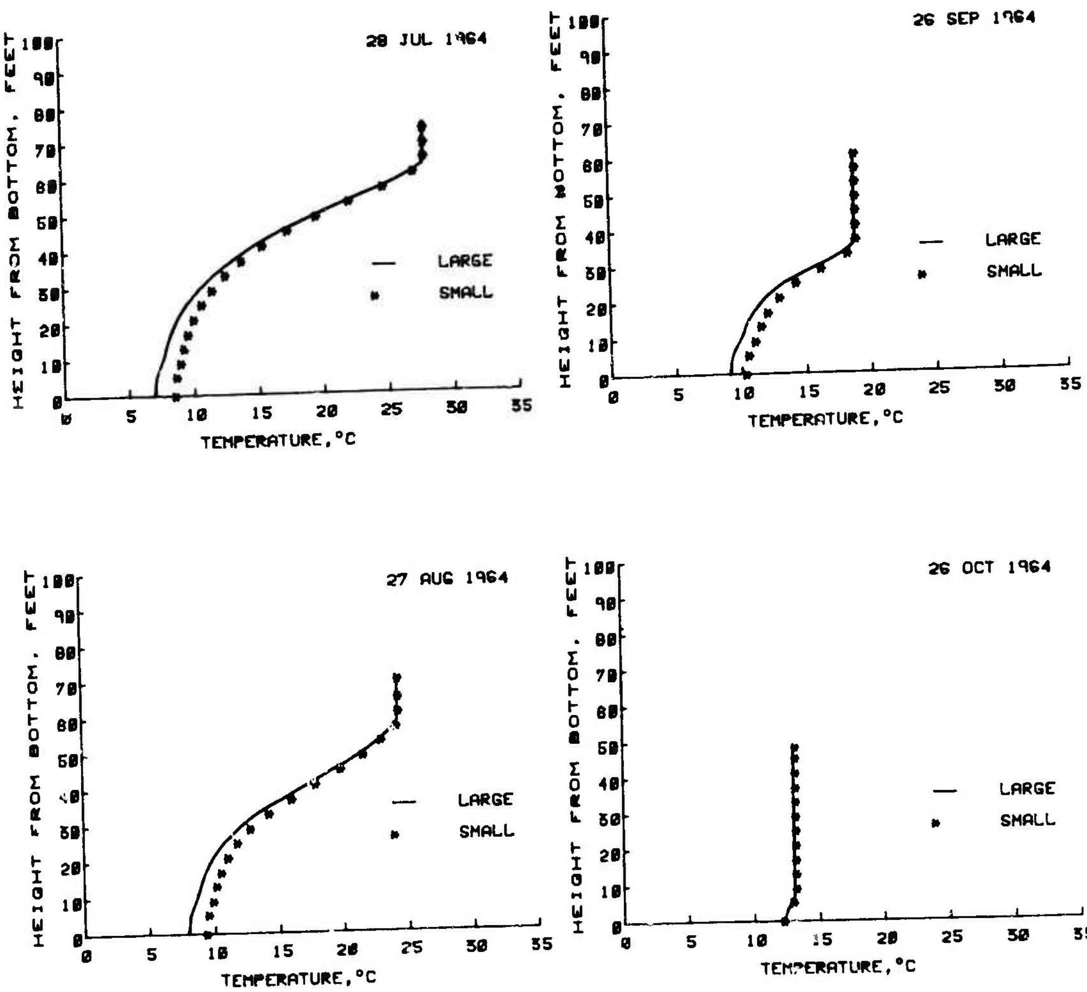

Plate 6T. Temperature profiles, pool el 1075.0, Jul-Oct 1964, with one additional level of large and small ports

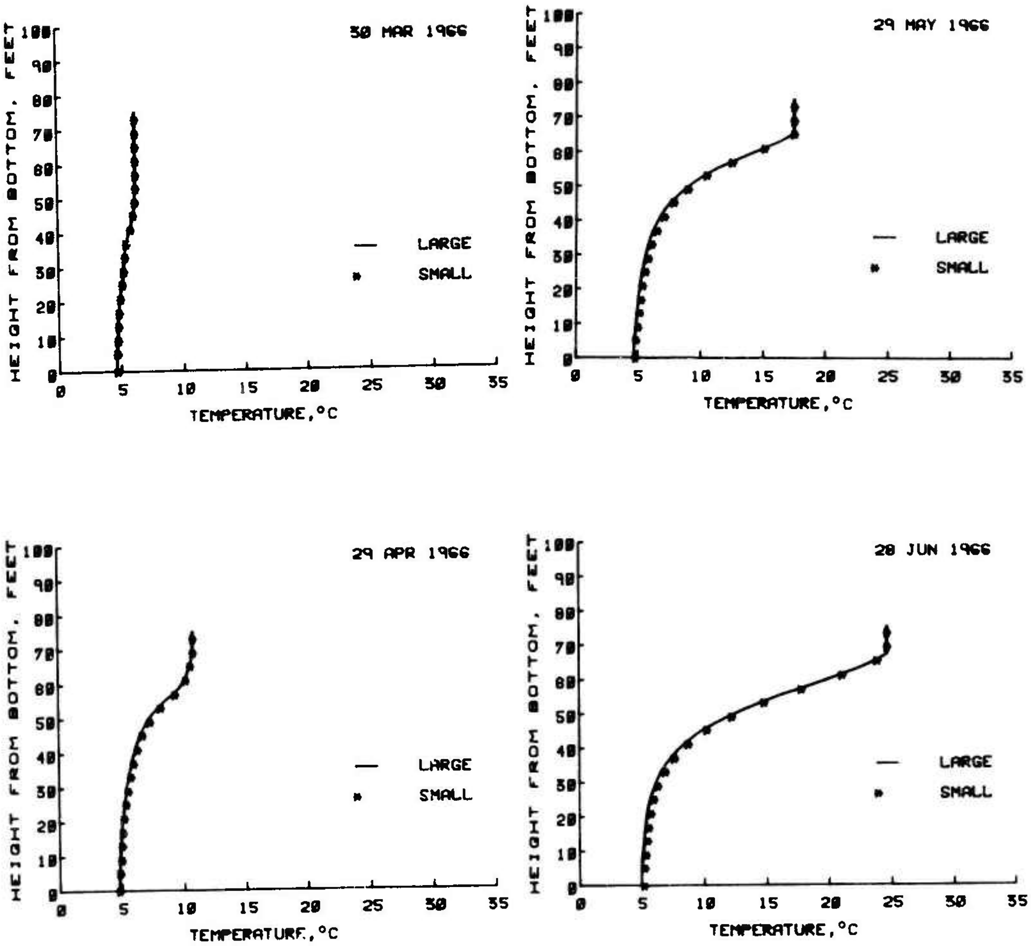

Plate 6U. Temperature profiles, pool el 1075.0, Mar-Jun 1966, with one additional level of large and small ports

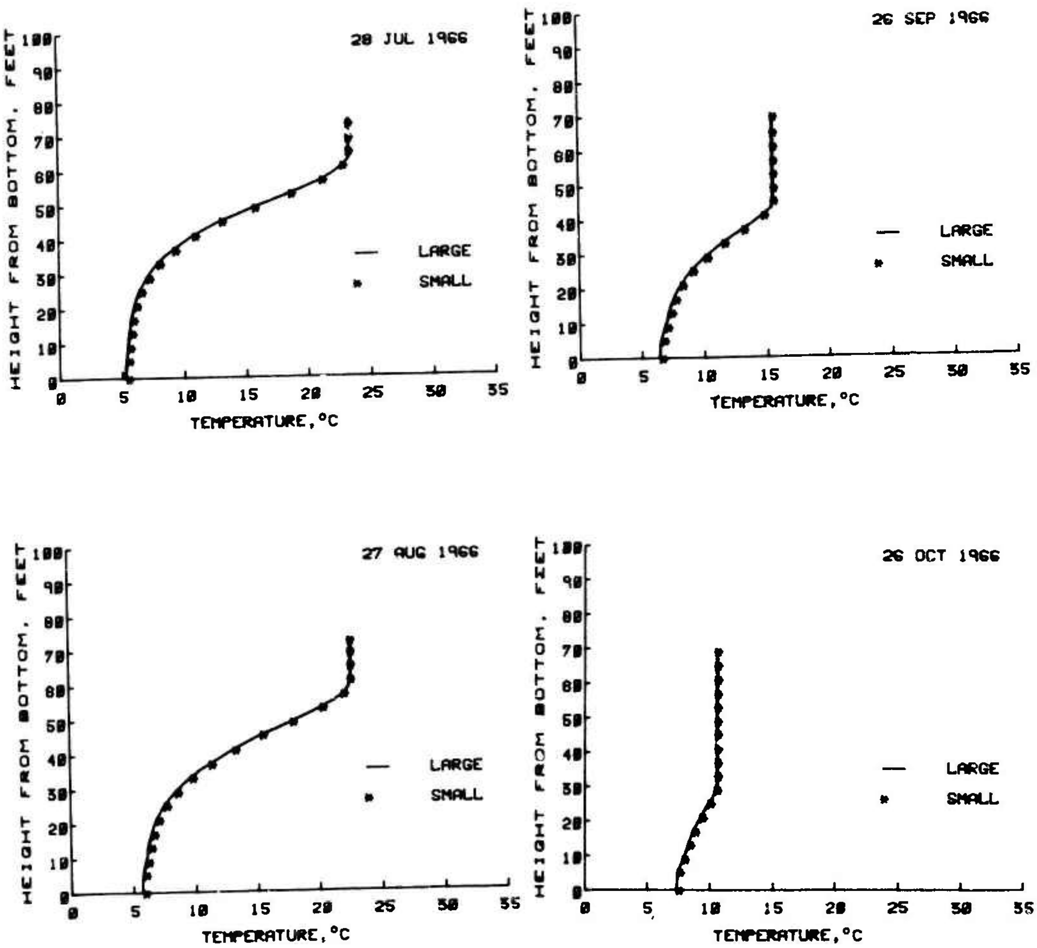

Plate 6V. Temperature profiles, pool el 1075.0, Jul-Oct 1966, with one additional level of large and small ports

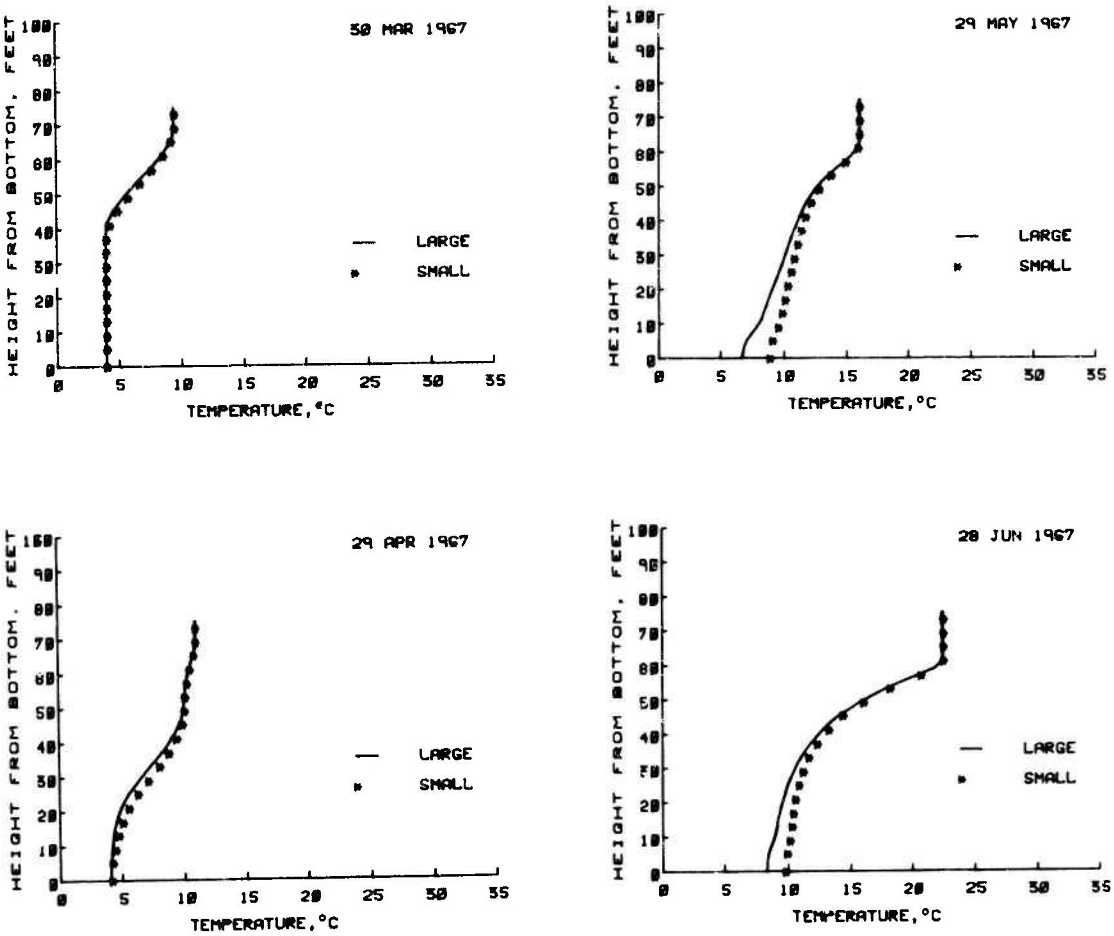

Plate 6W. Temperature profiles, pool el 1075.0, Mar-Jun 1967, with one additional level of large and small ports

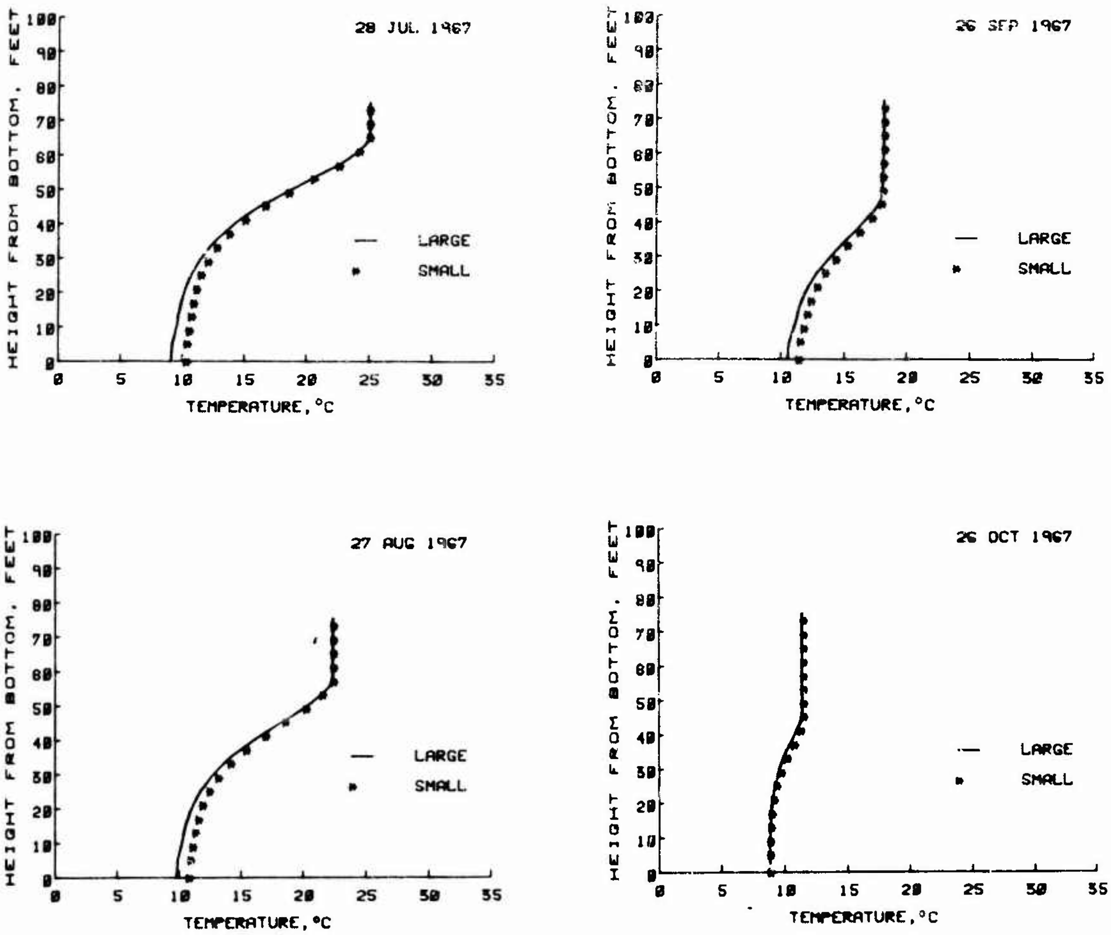

Plate 6X. Temperature profiles, pool el 1075.0, Jul-Oct 1967, with one additional level of large and small ports

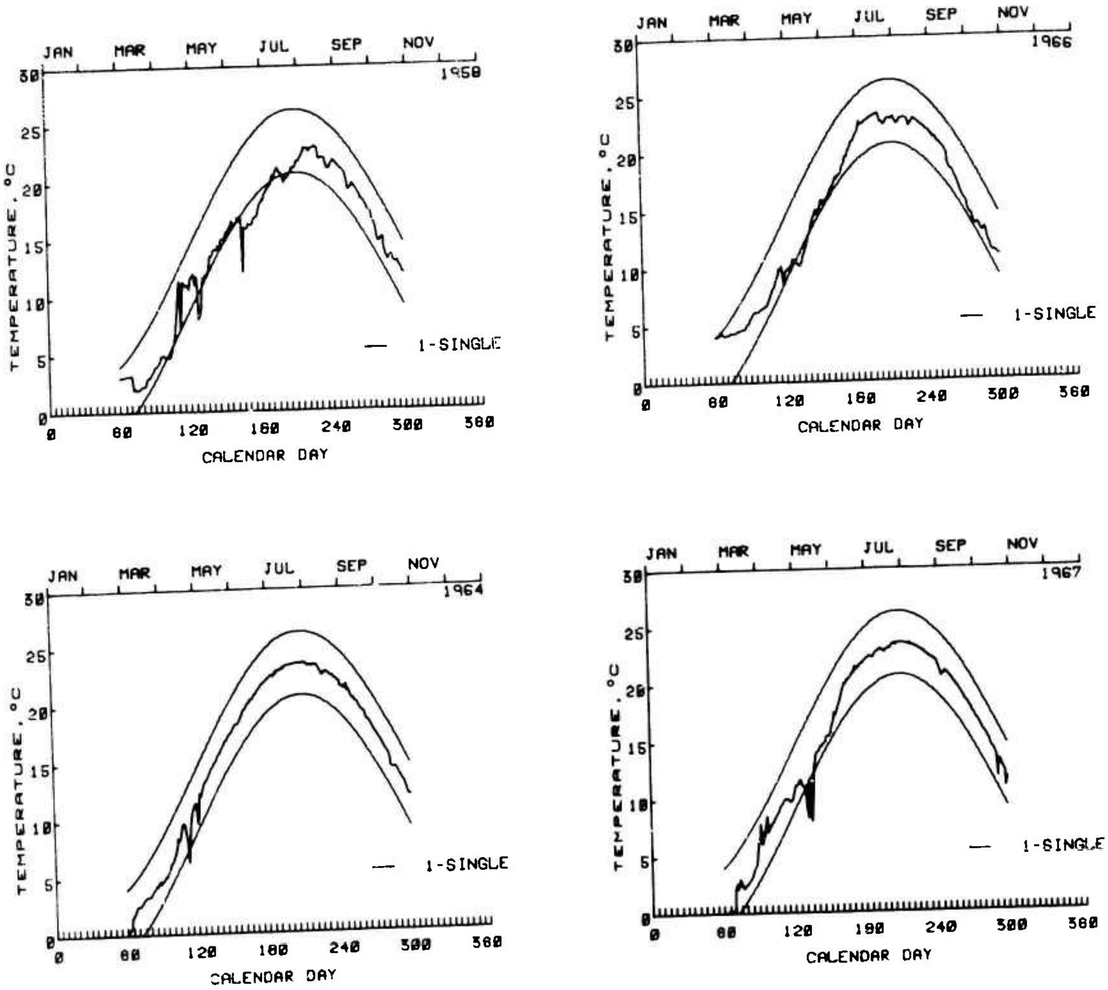

Plate 7A. Predicted daily release temperatures with single optimum port configuration, pool el 1085.0

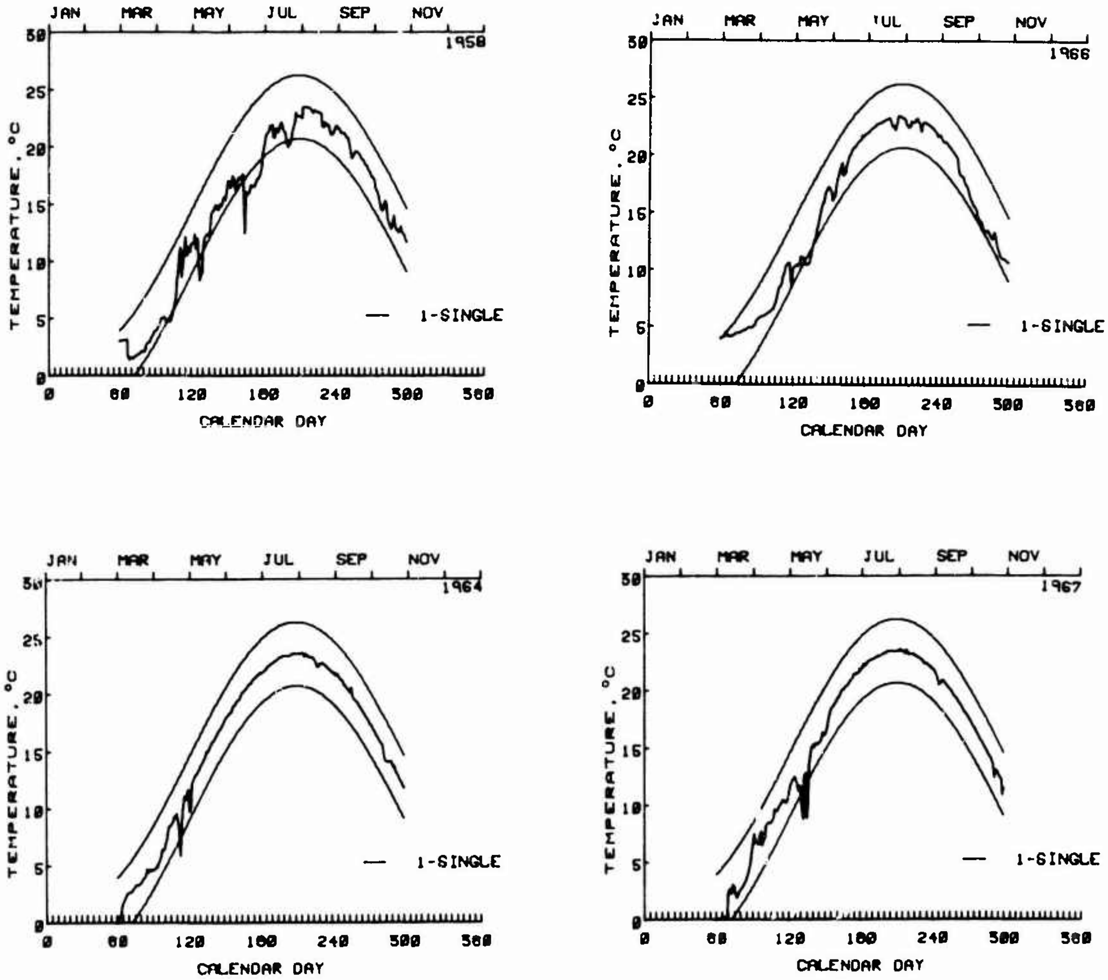

Plate 7B. Predicted daily release temperatures with single optimum port configuration, pool el 1080.0

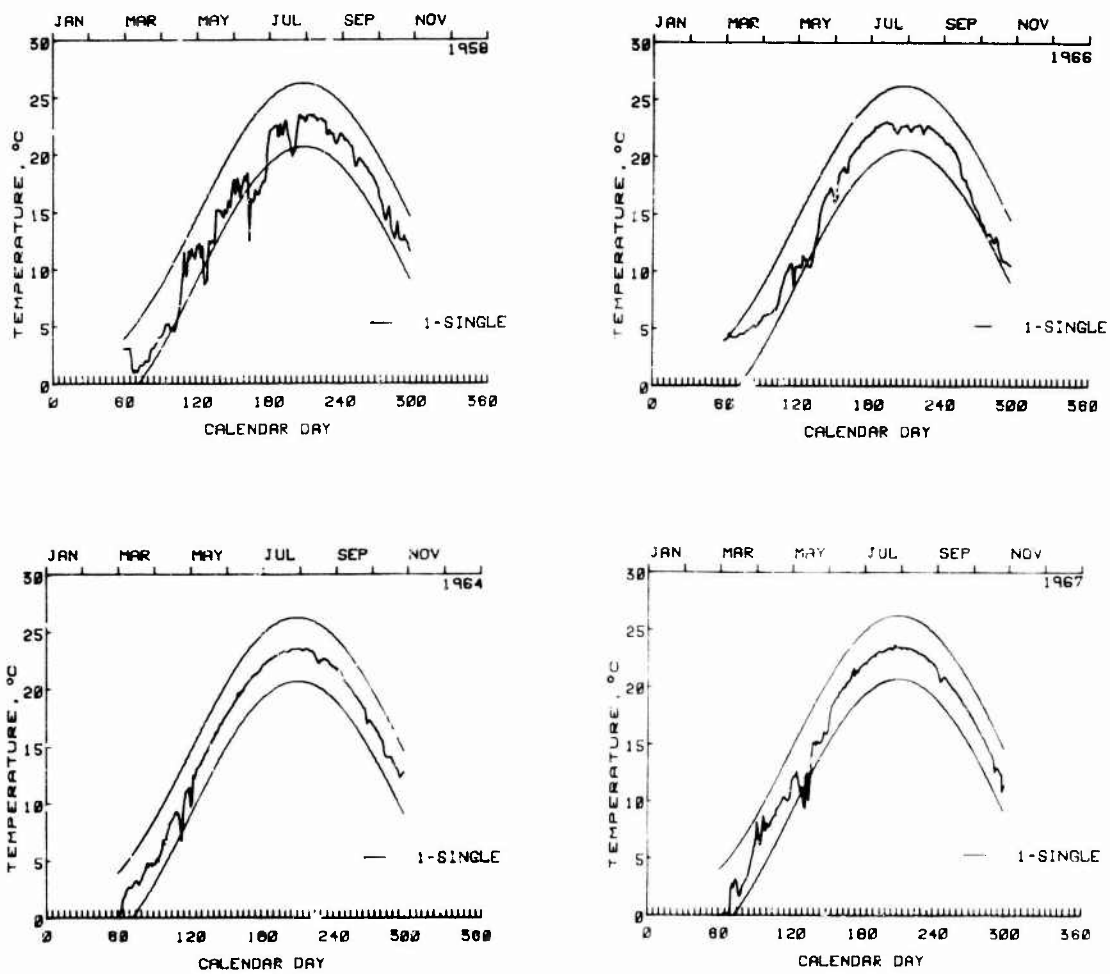

Plate 7C. Predicted daily release temperatures with single optimum port configuration, pool el 1075.0

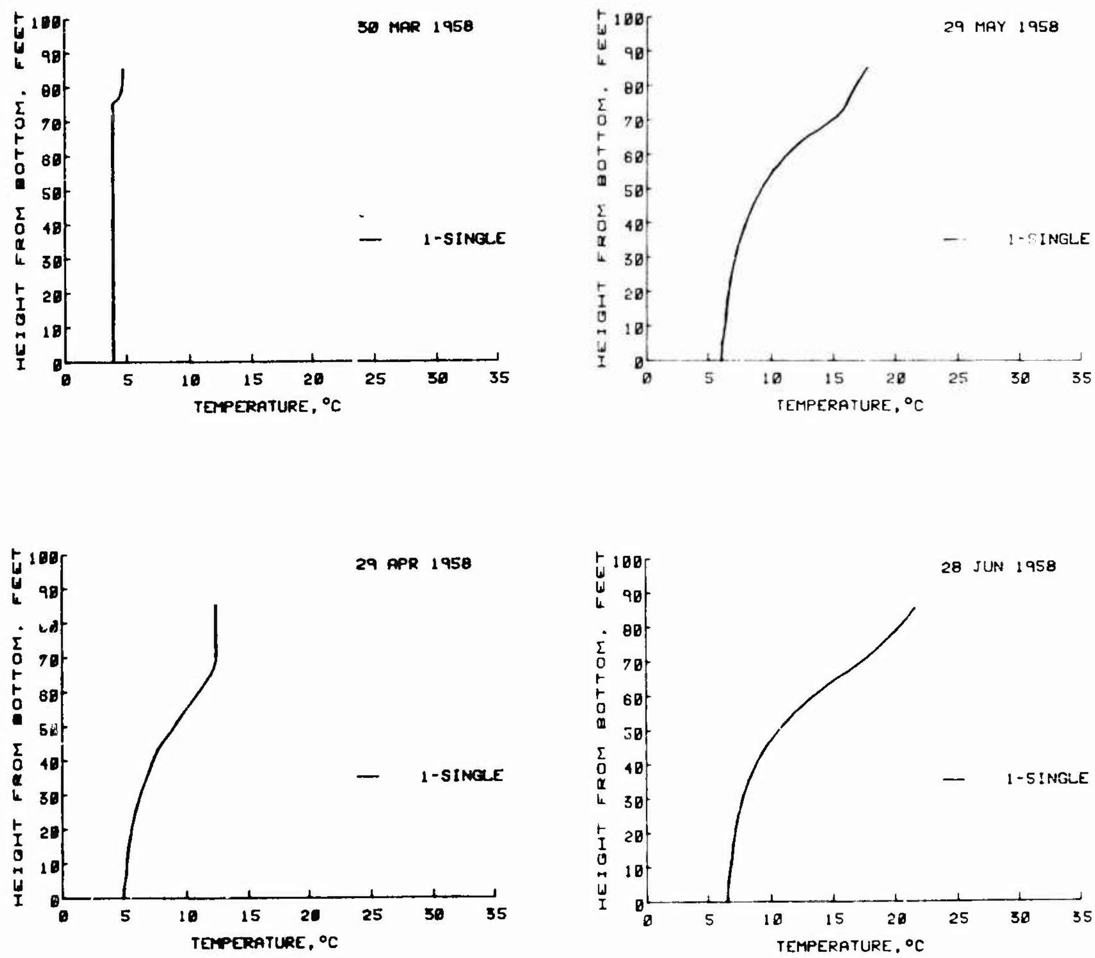

Plate 8A. Temperature profiles with single optimum port configuration, pool el 1085.0, Mar-Jun 1958

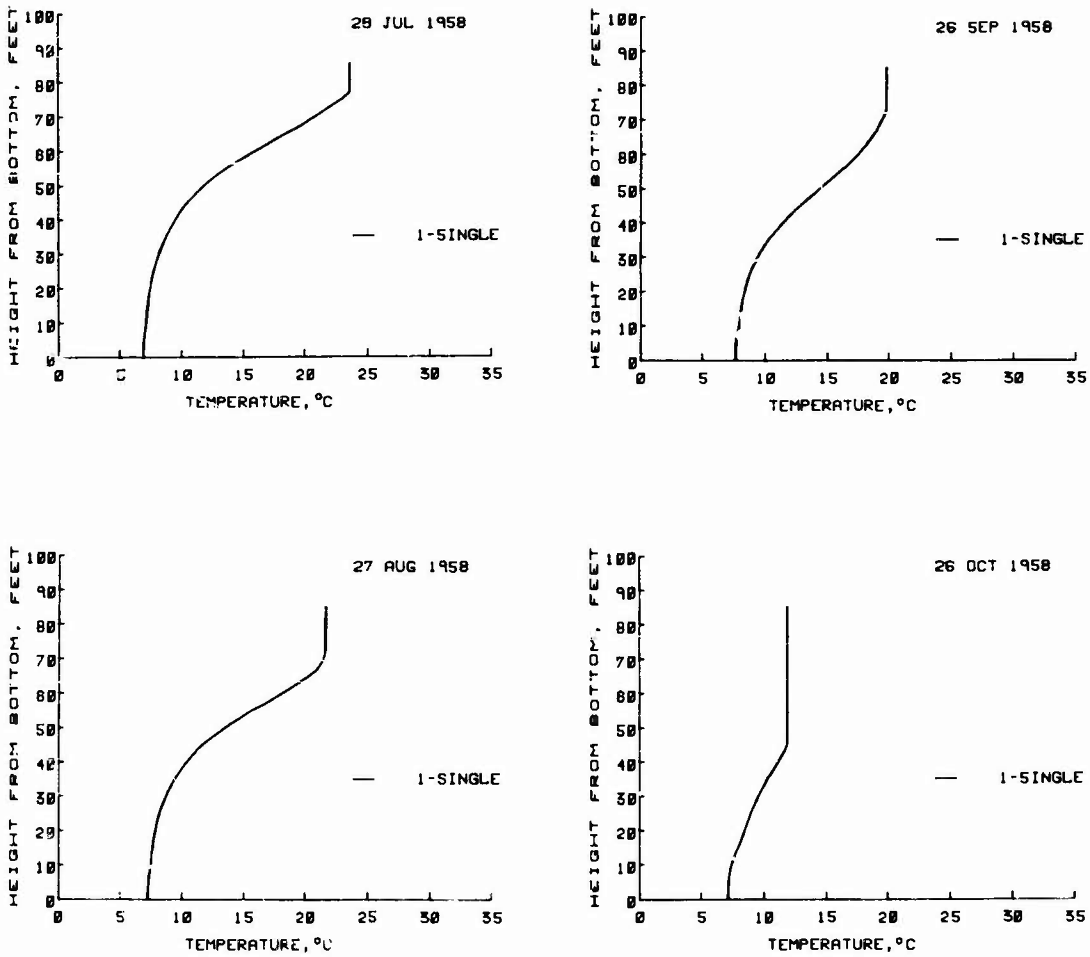

Plate 8B. Temperature profiles with single optimum port configuration, pool el 1085.0, Jul-Oct 1958

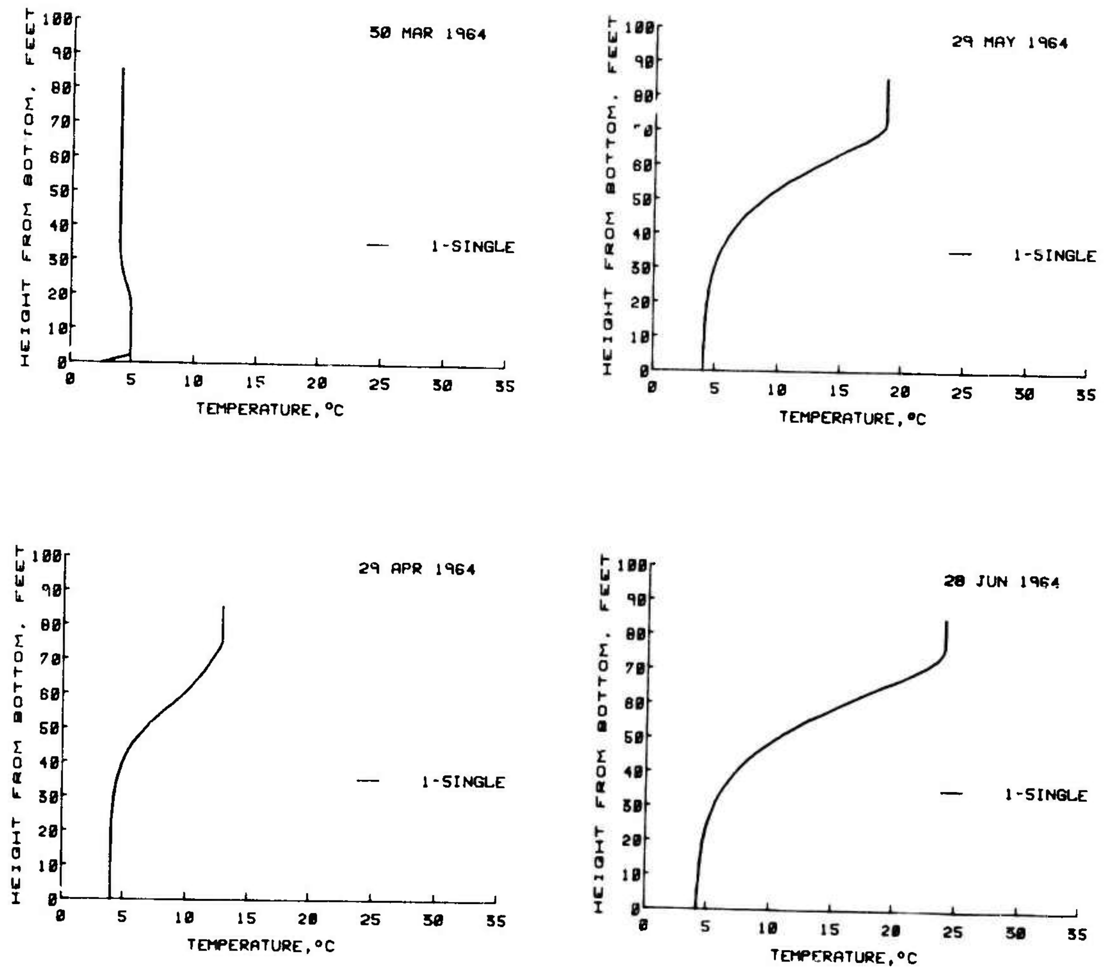

Plate 8C. Temperature profiles with single optimum port configuration, pool el 1085.0, Mar-Jun 1964

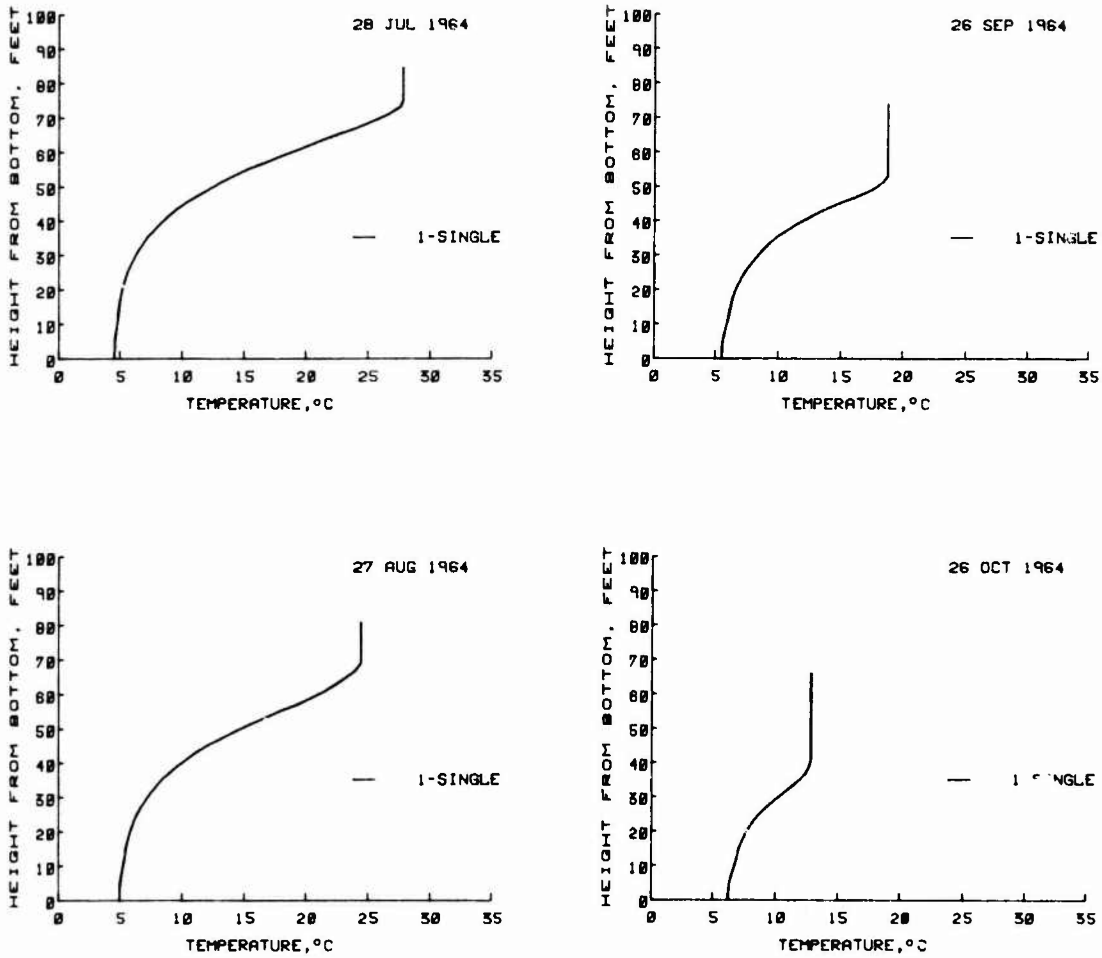

Plate 8D. Temperature profiles with single optimum port configuration, pool el 1085.0, Jul-Oct 1964

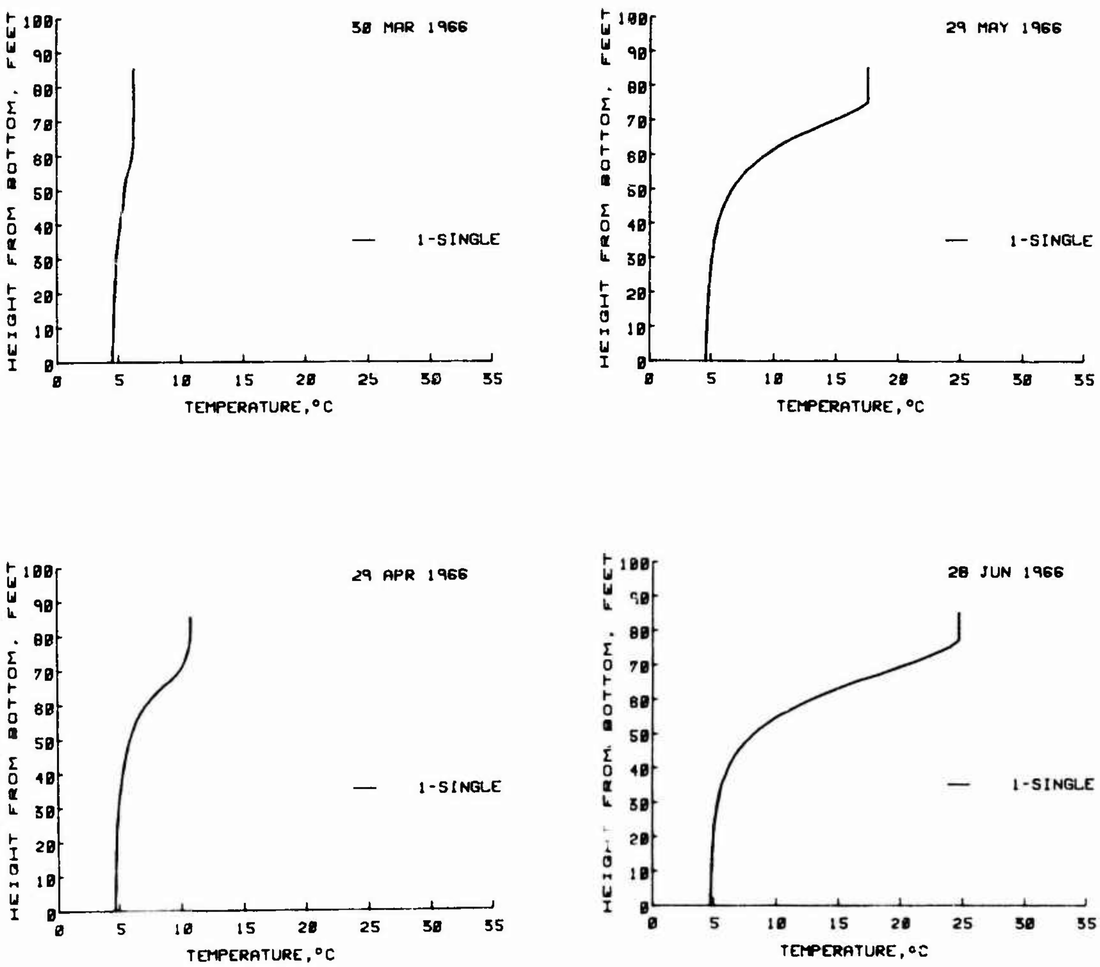

Plate 8E. Temperature profiles with single optimum port configuration, pool el 1085.0, Mar-Jun 1966

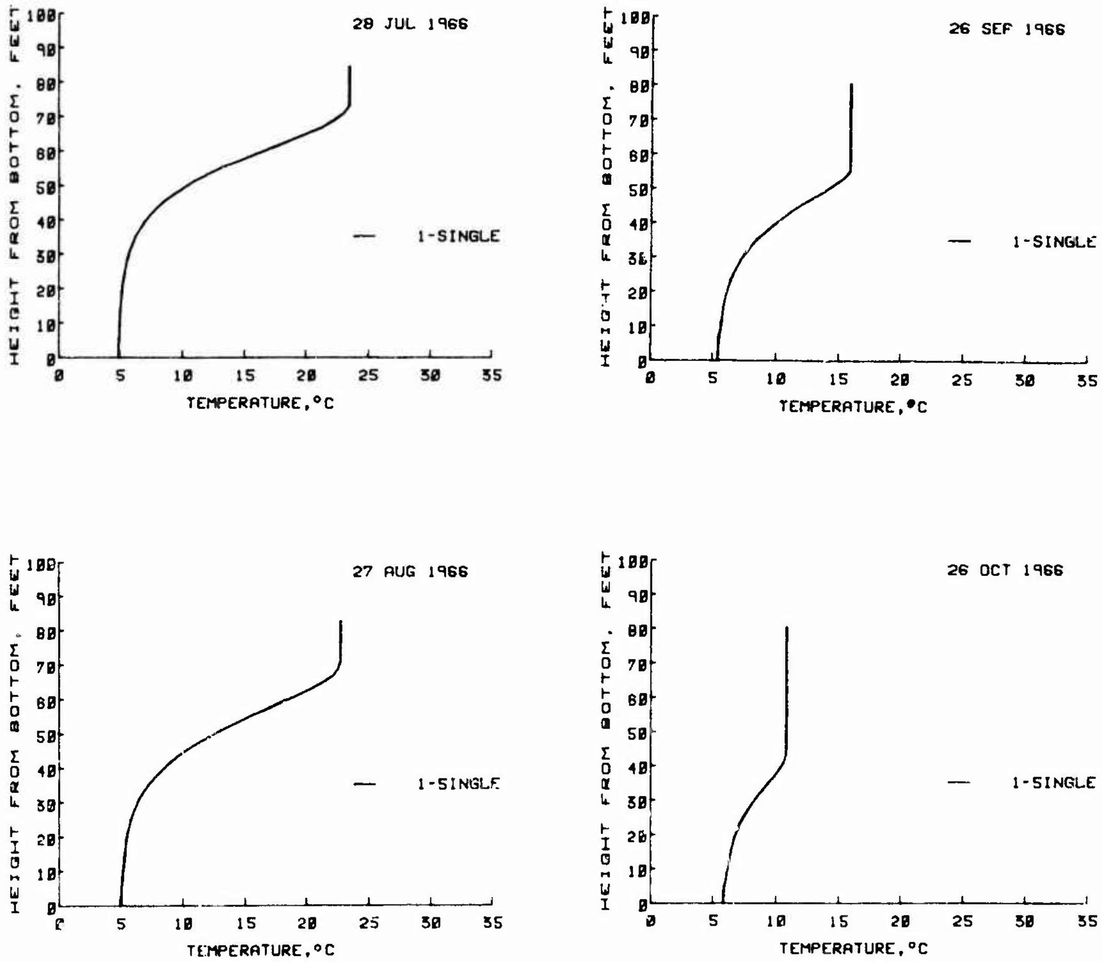

Plate 8F. Temperature profiles with single optimum port configuration, pool el 1085.0, Jul-Oct 1966

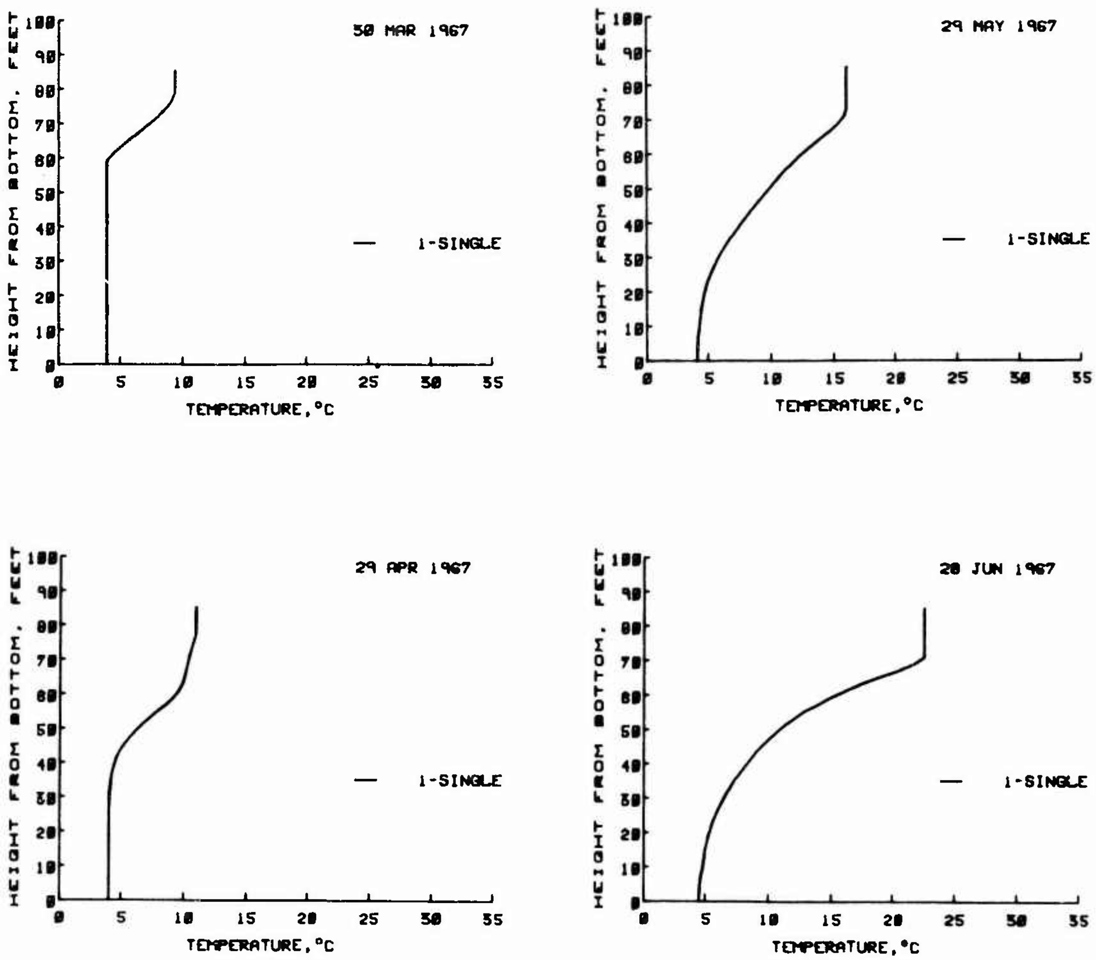

Plate 8G. Temperature profiles with single optimum port configuration, pool el 1085.0, Mar-Jun 1967

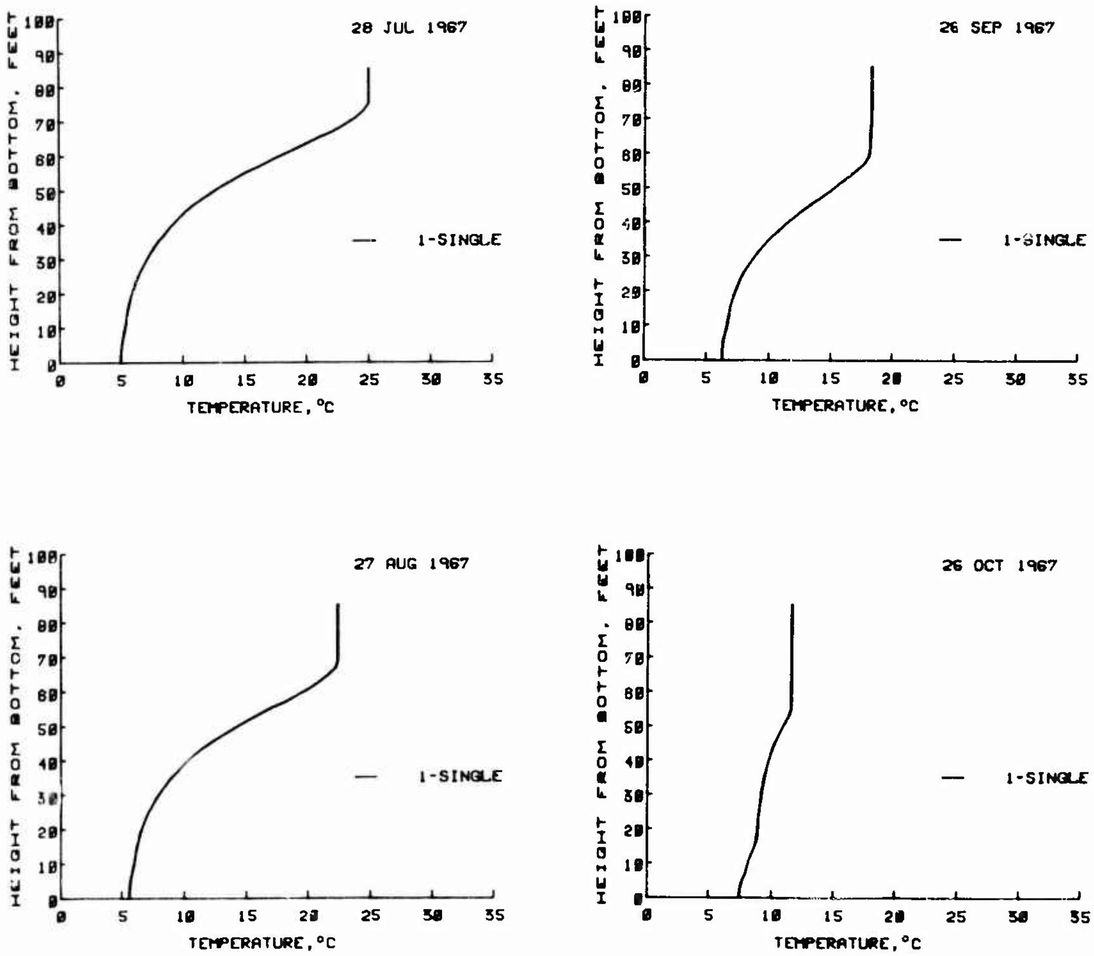

Plate 8H. Temperature profiles with single optimum port configuration, pool el 1085.0, Jul-Oct 1967

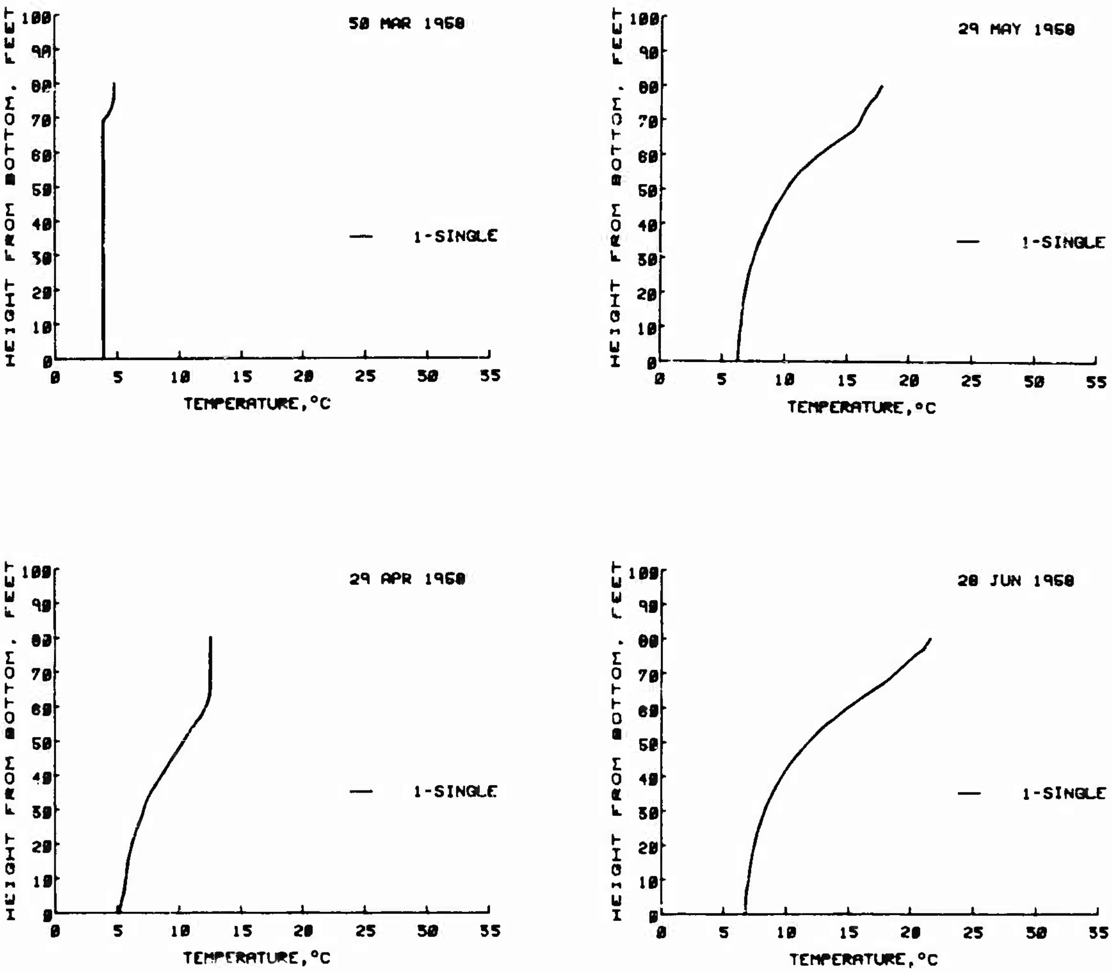

Plate 81. Temperature profiles with single optimum port configuration, pool el 1080.0, Mar–Jun 1958

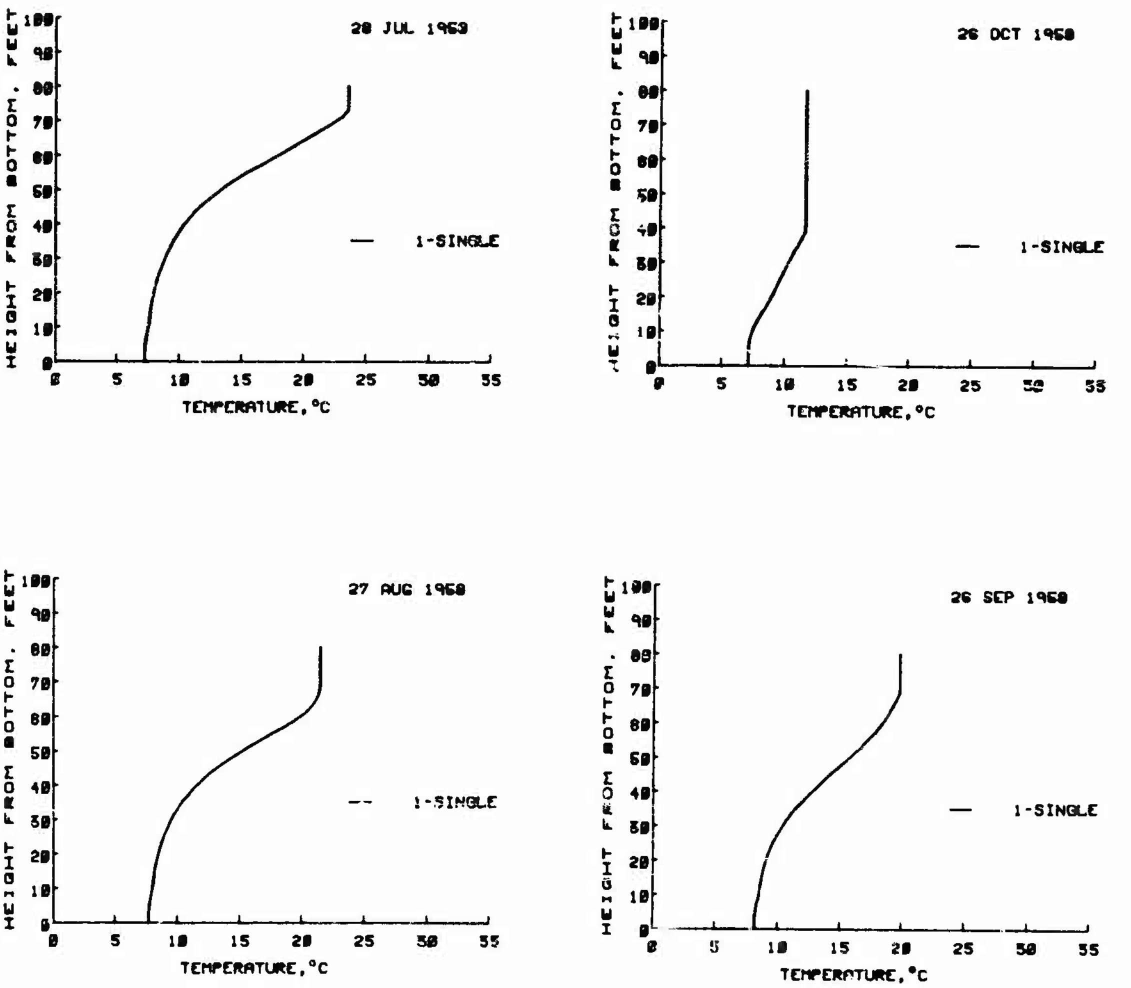

Plate 8J. Temperature profiles with single optimum port configuration, pool el 1080.0, Jul-Oct 1958

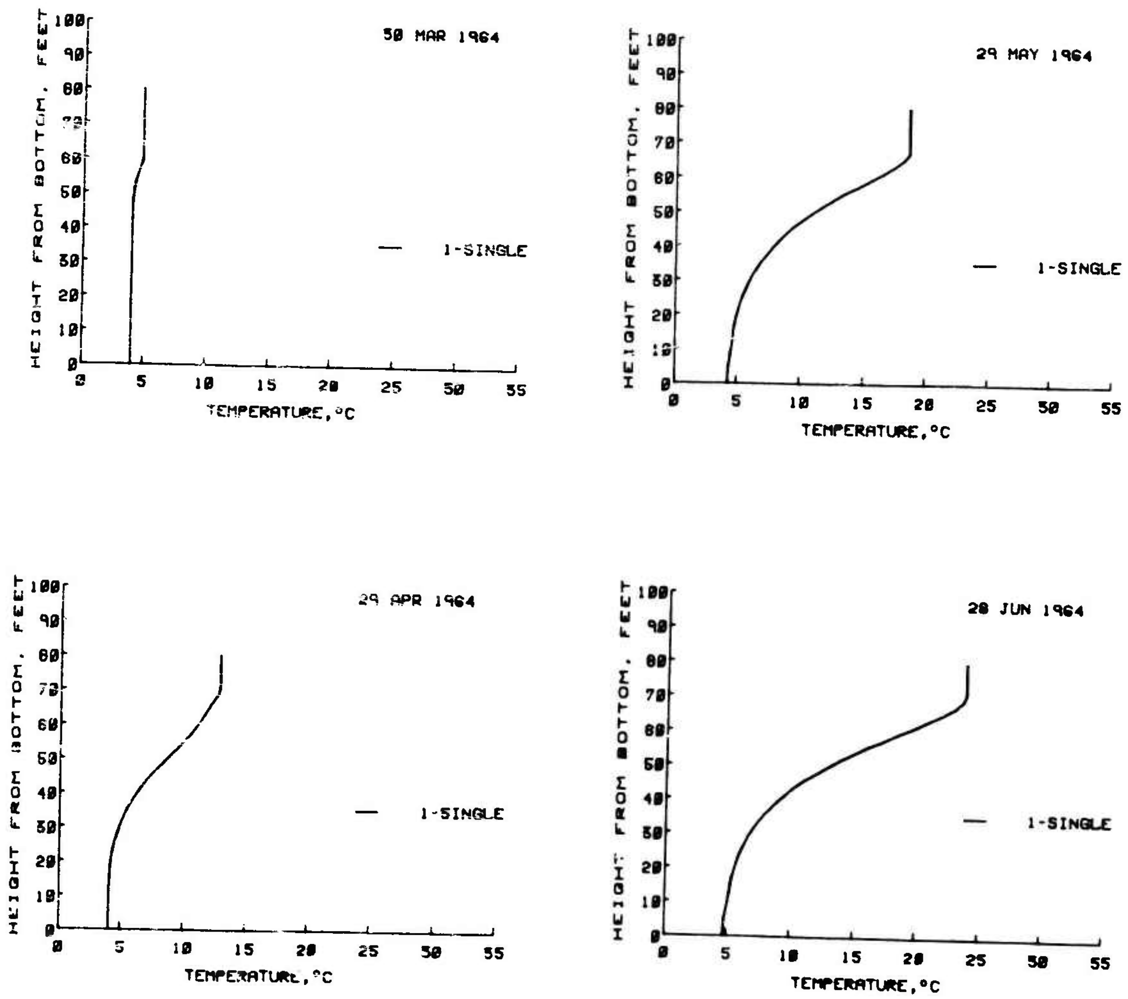

Plate 8K. Temperature profiles with single optimum port configuration, pool el 1080.0, Mar-Jun 1964

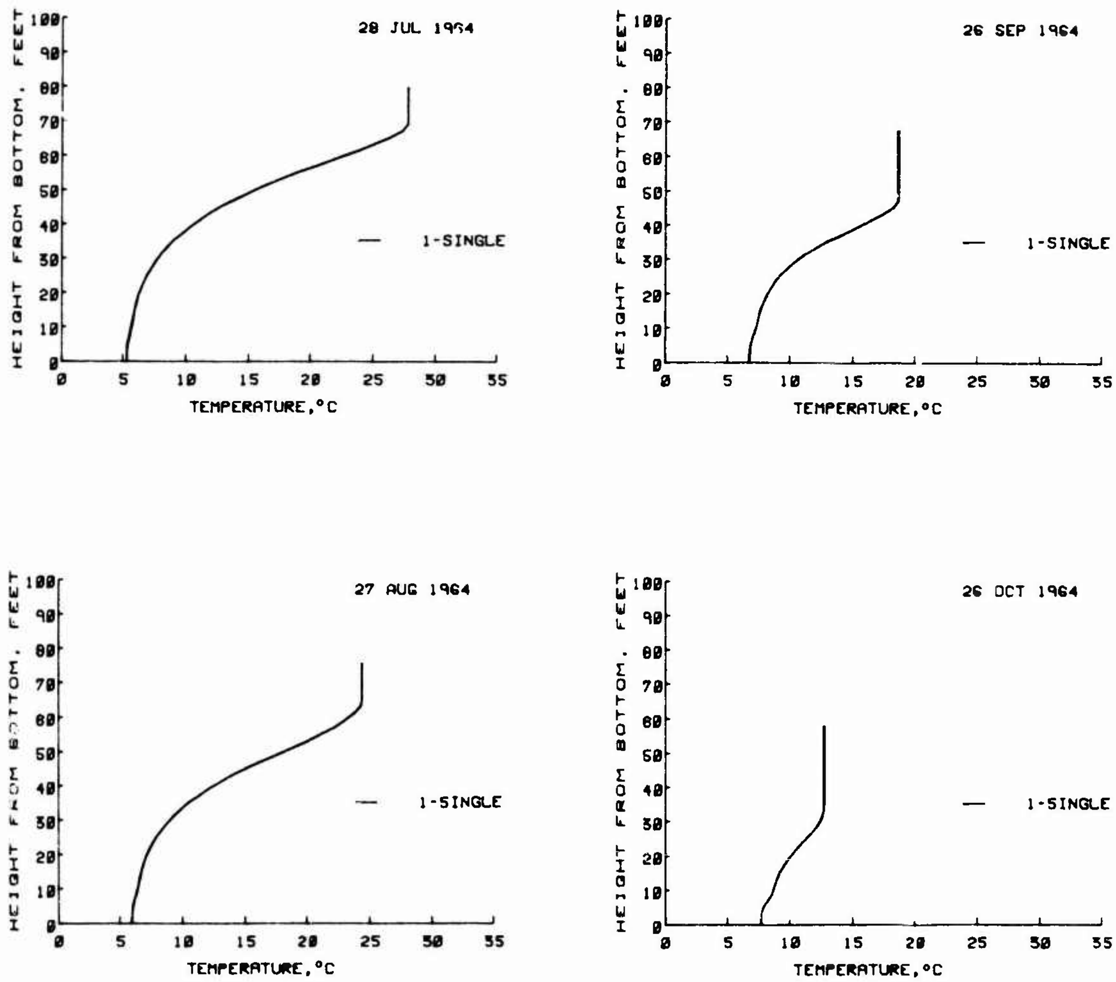

Plate 8L. Temperature profiles with single optimum port configuration, pool el 1080.0, Jul-Oct 1964

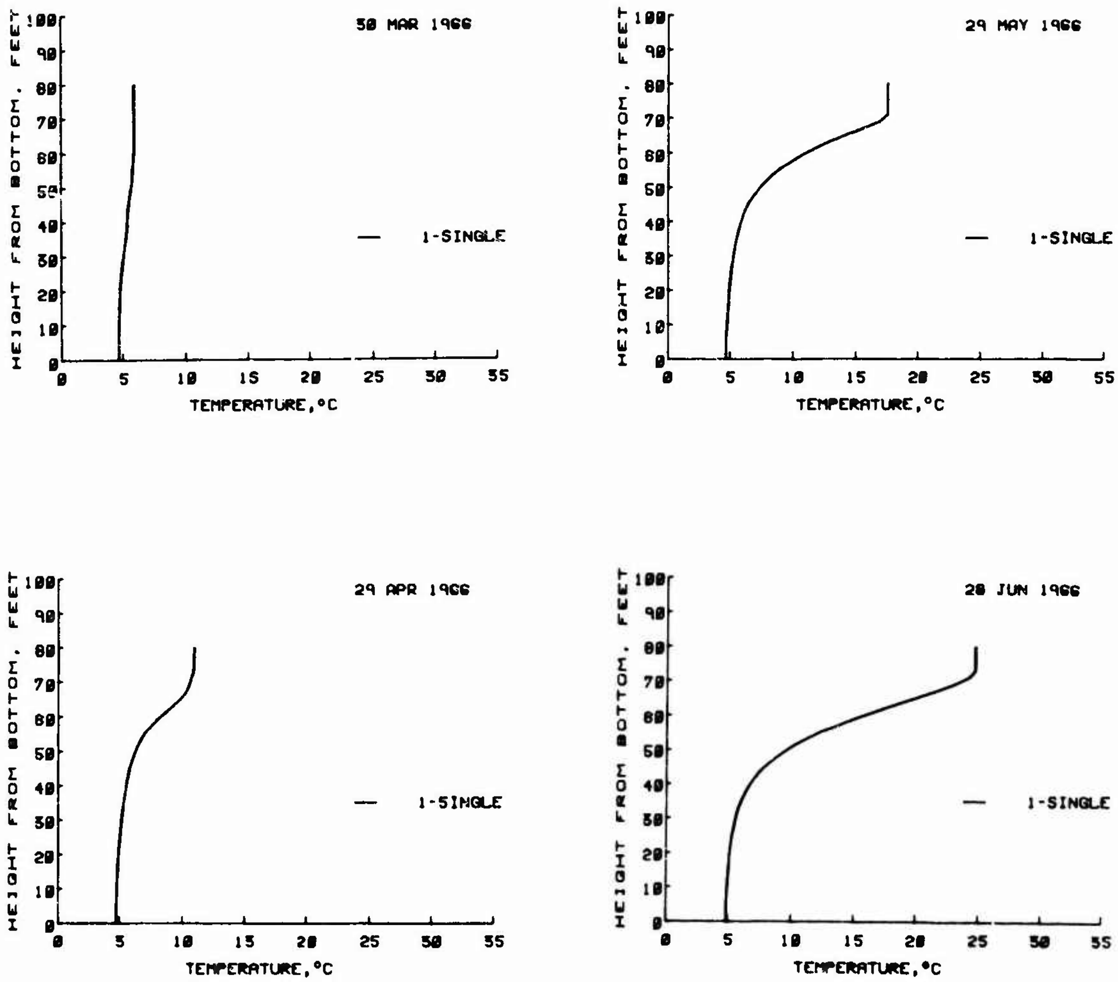

Plate 8M. Temperature profiles with single optimum port configuration, pool el 1080.0, Mar-Jun 1966

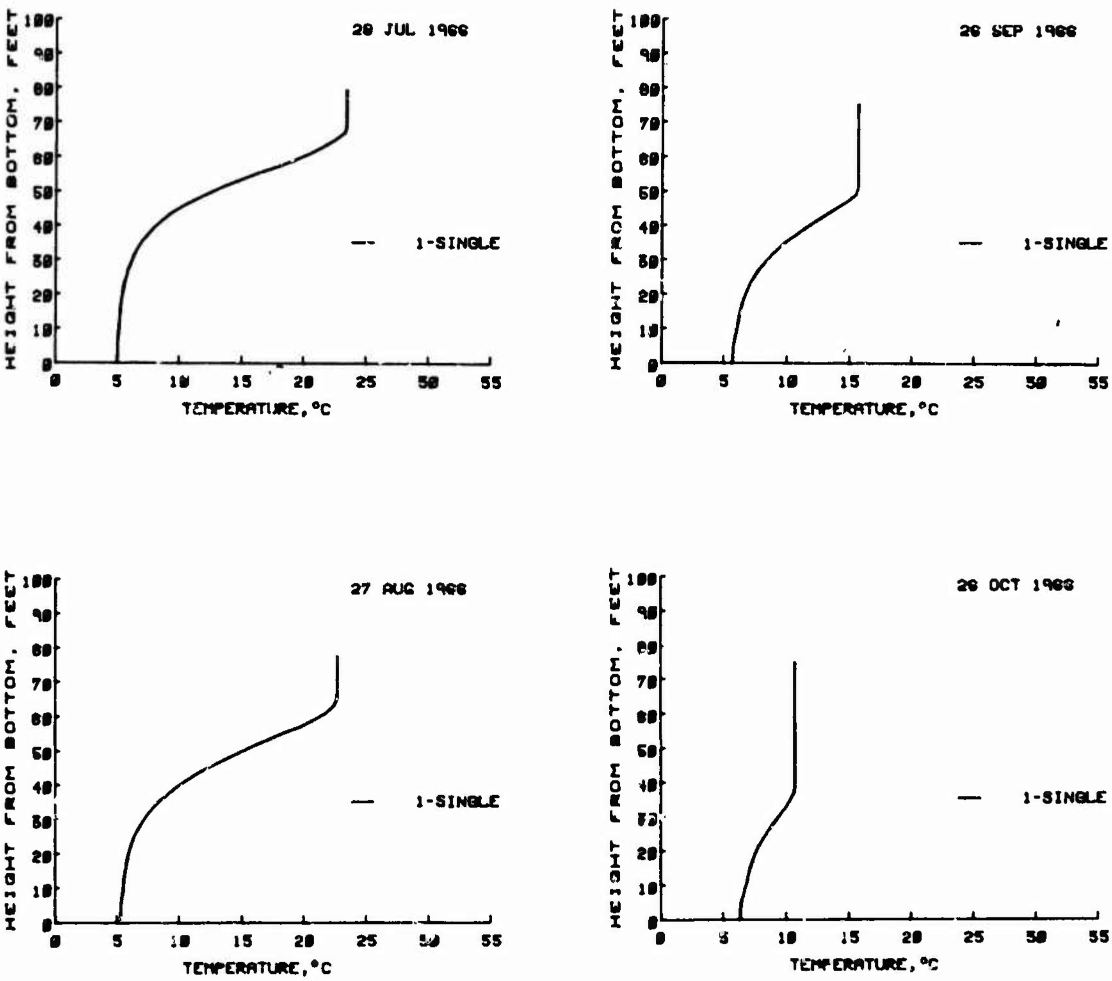

Plate 8N. Temperature profiles with single optimum port configuration, pool el 1080.0, Jul-Oct 1966

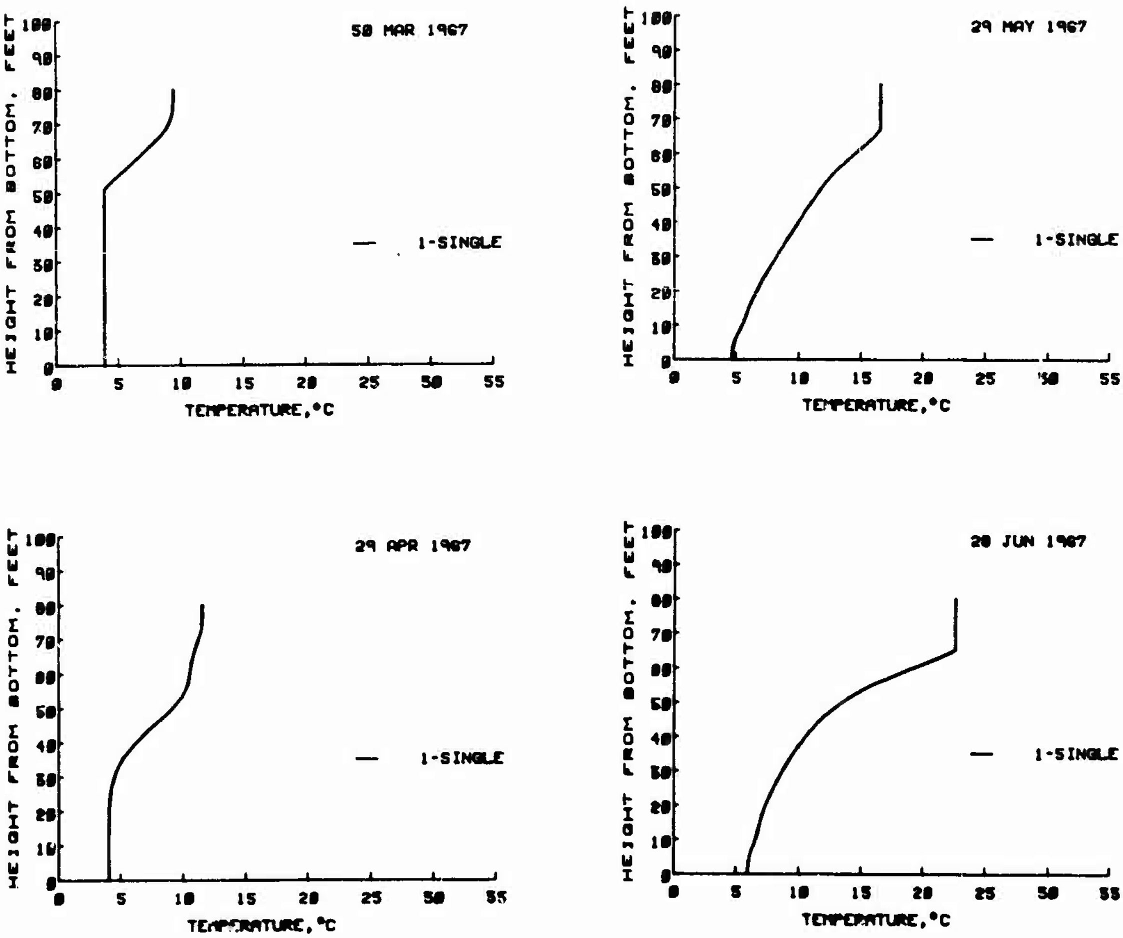

Plate 80. Temperature profiles with single optimum port configuration, pool el 1080.0, Mar-Jun 1967

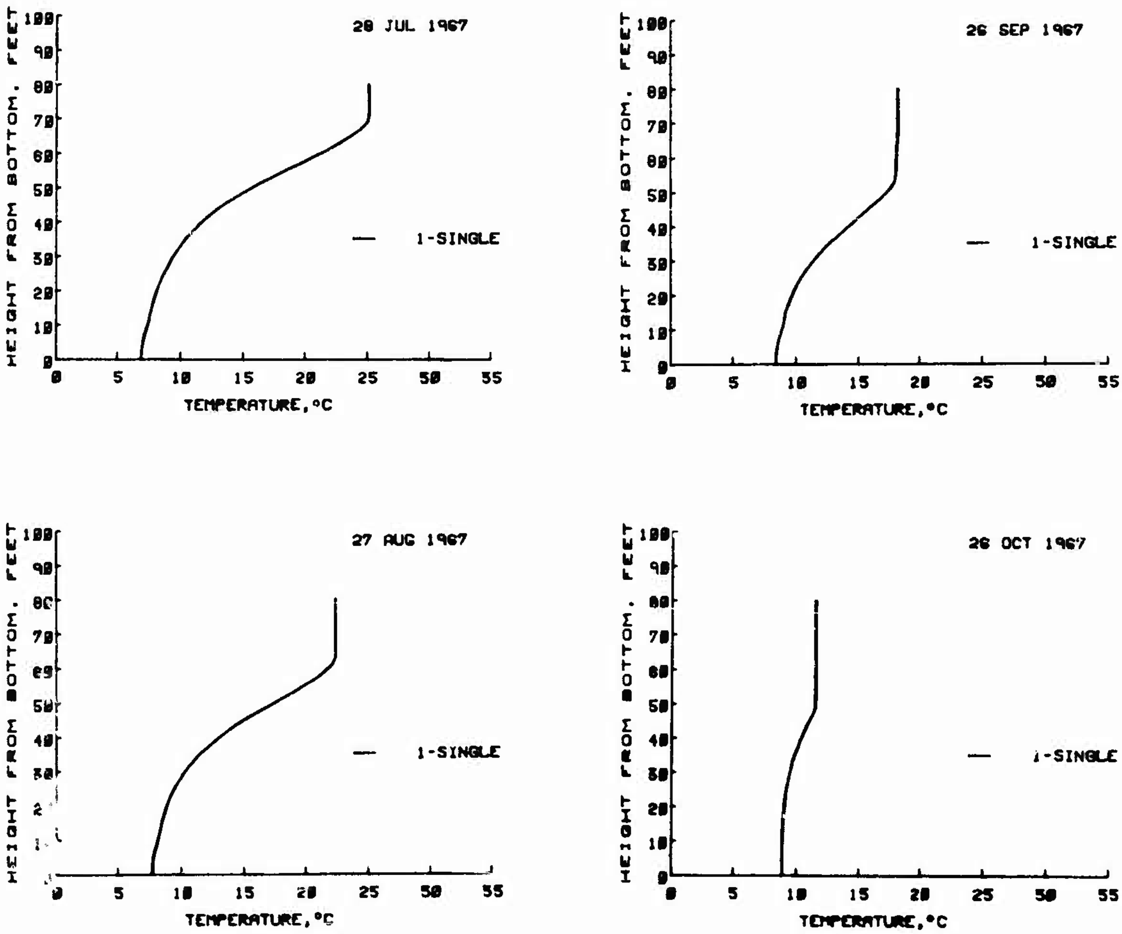

Plate 8P. Temperature profiles with single optimum port configuration, pool el 1080.0, Jul-Oct 1967

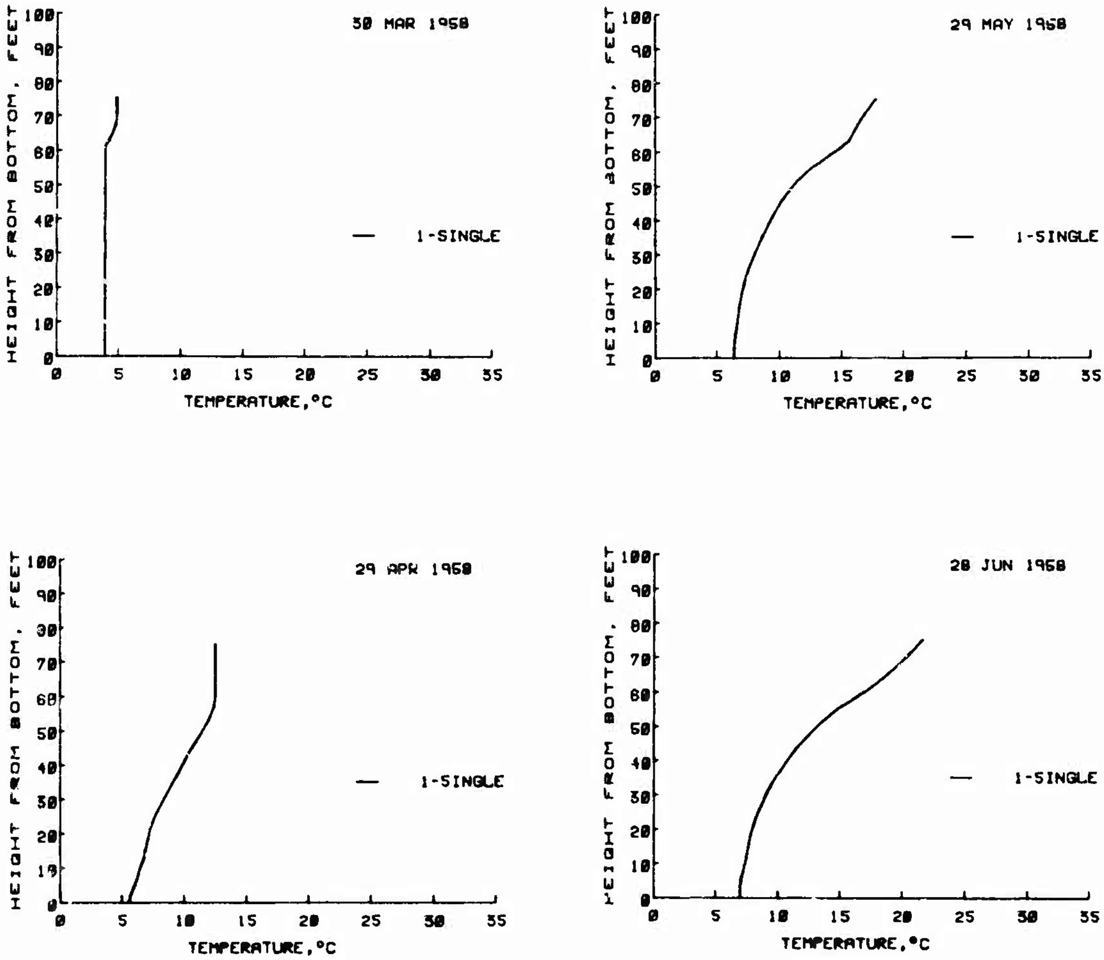

Plate 8Q. Temperature profiles with single optimum port configuration, pool el 1075.0, Mar-Jun 1958

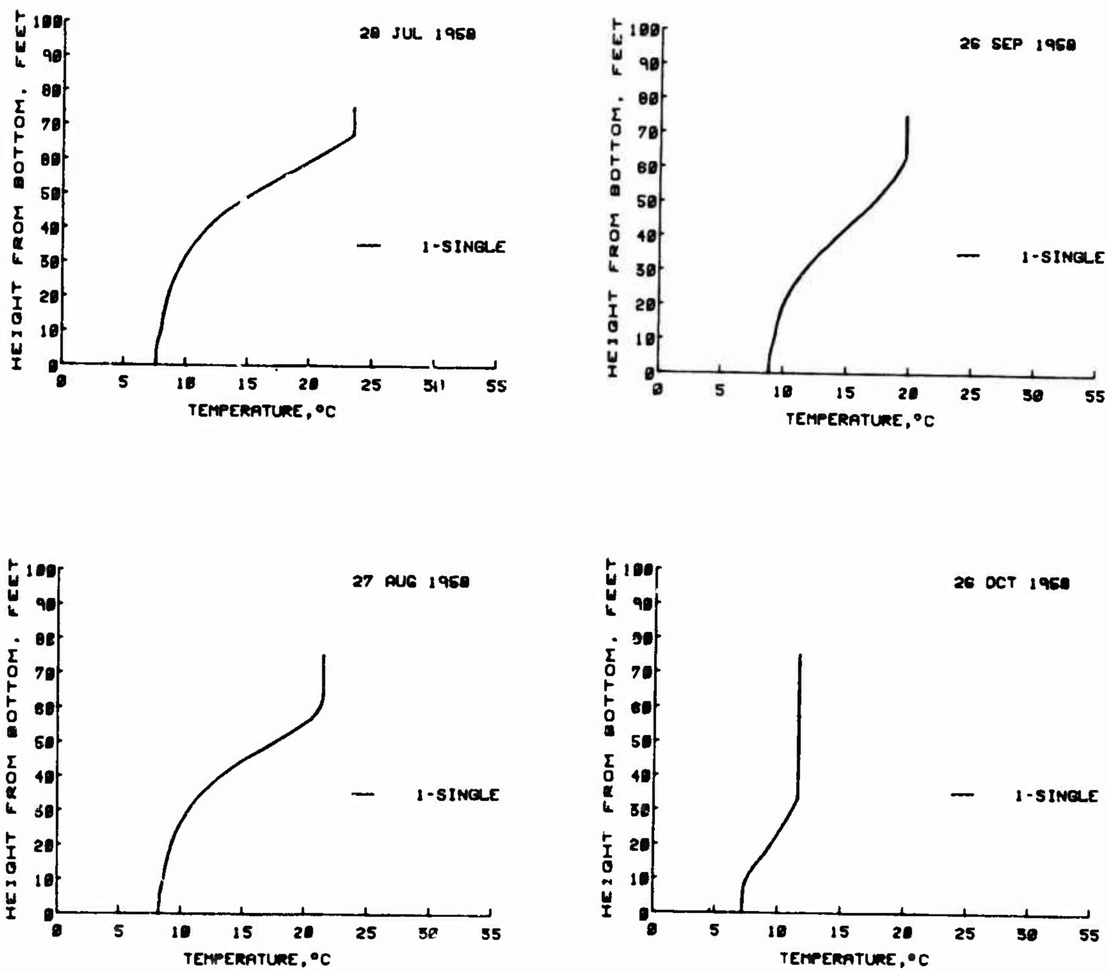

Plate 8R. Temperature profiles with single optimum port configuration, pool el 1075.0, Jul-Oct 1958

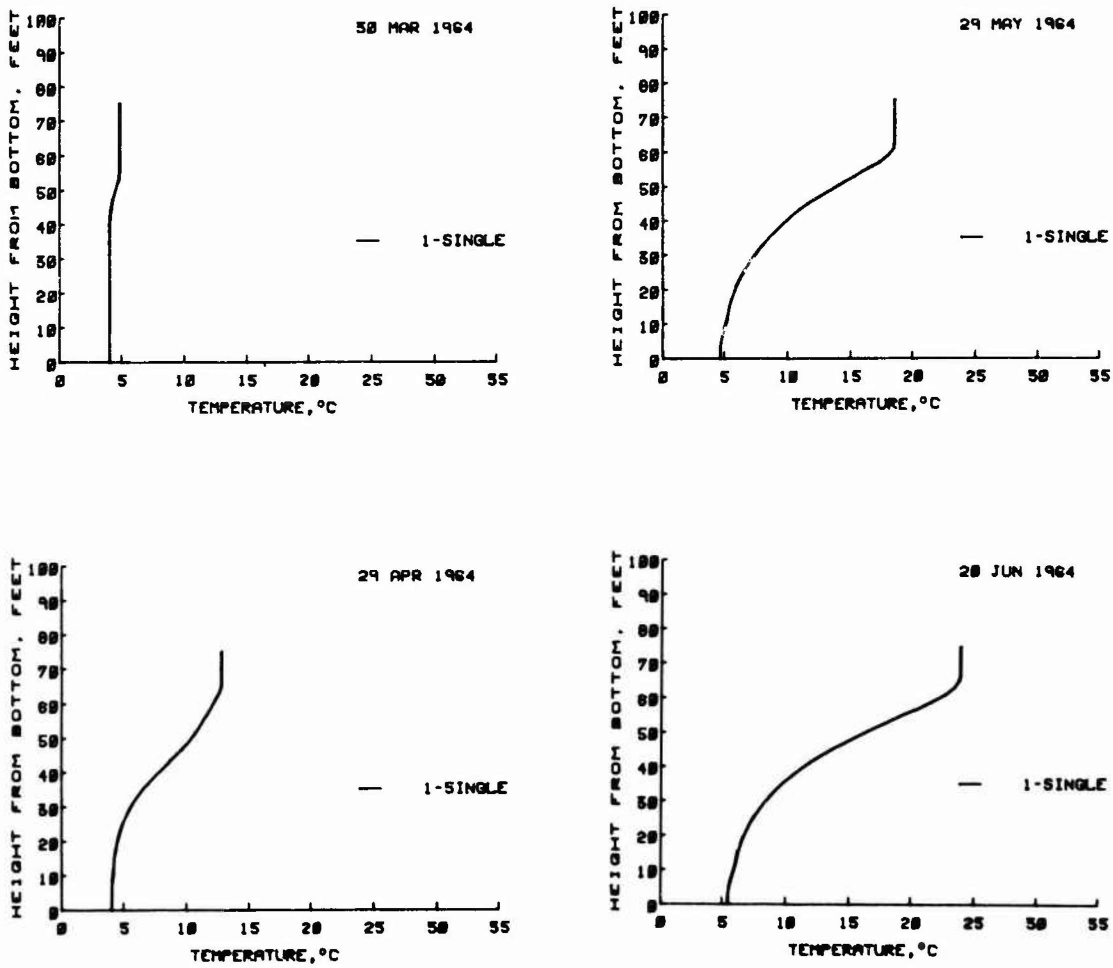

Plate 8S. Temperature profiles with single optimum port configuration, pool el 1075.0, Mar-Jun 1964

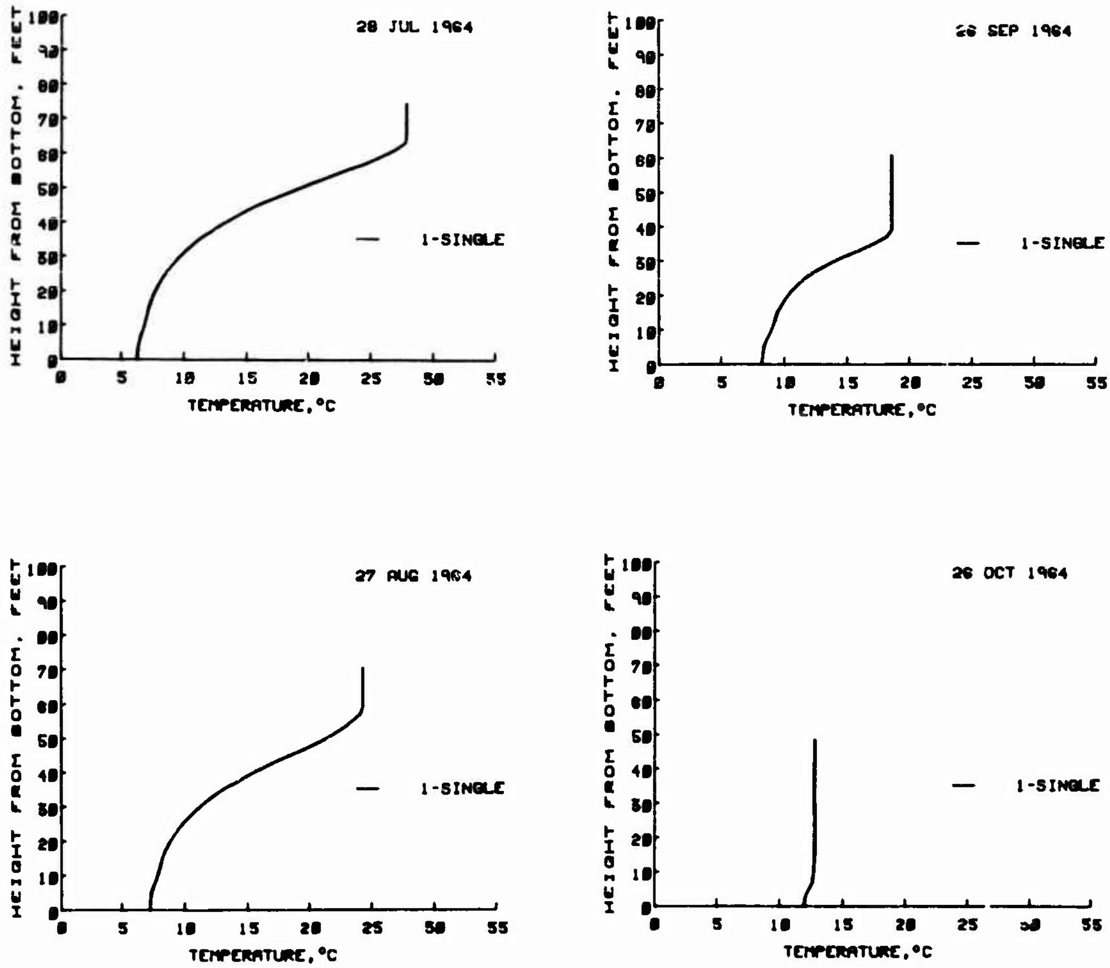

Plate 8T. Temperature profiles with single optimum port configuration, pool el 1075.0, Jul-Oct 1964

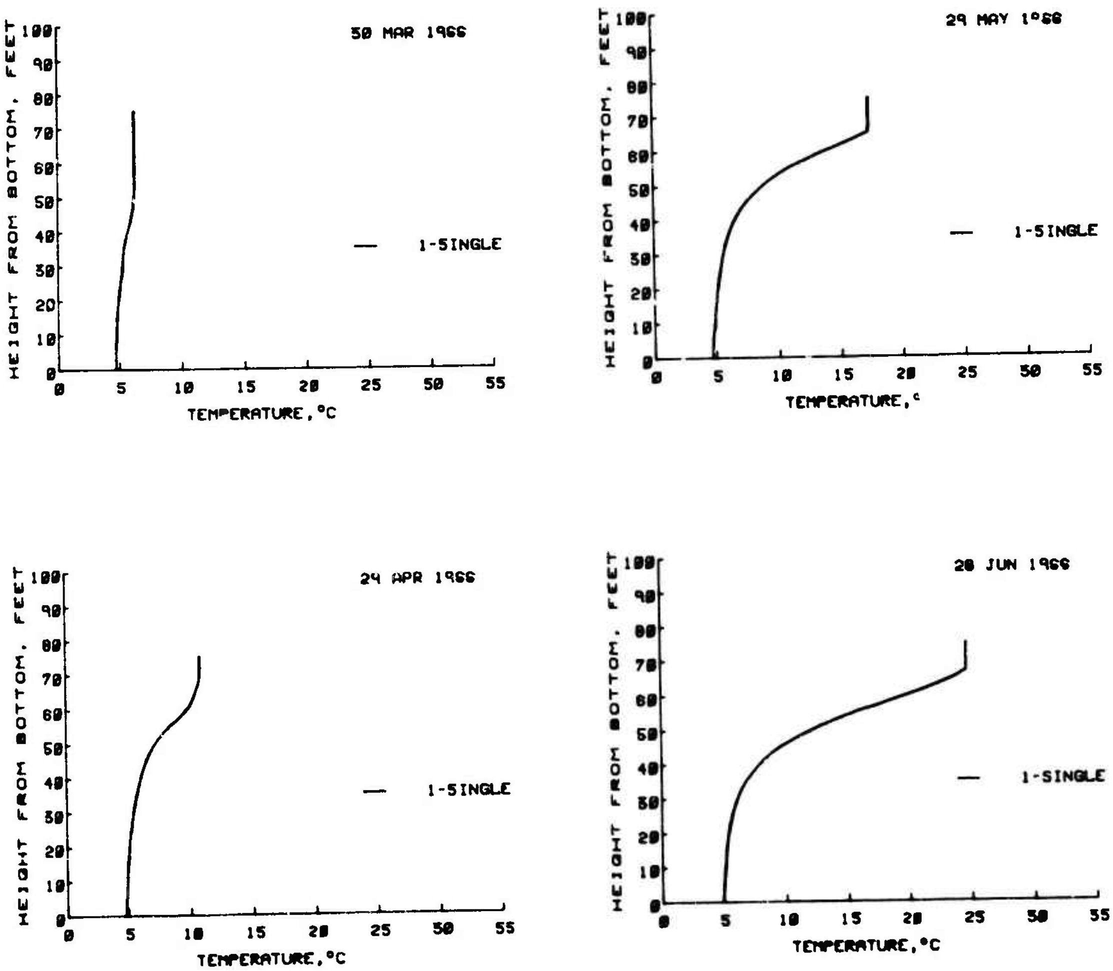

Plate 8U. Temperature profiles with single optimum port configuration, pool el 1075.0, Mar-Jun 1966

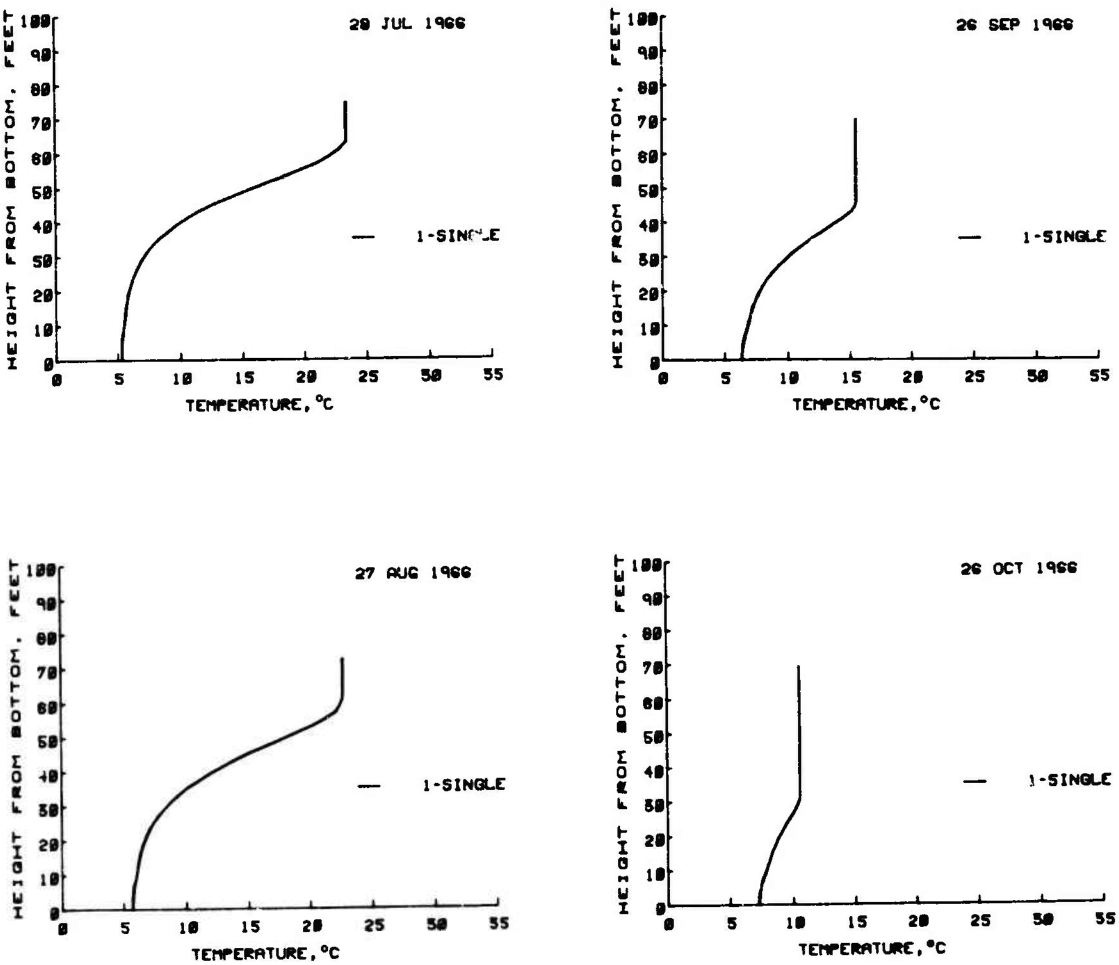

Plate 8V. Temperature profiles with single optimum port configuration, pool el 1075.0, Jul-Oct 1966

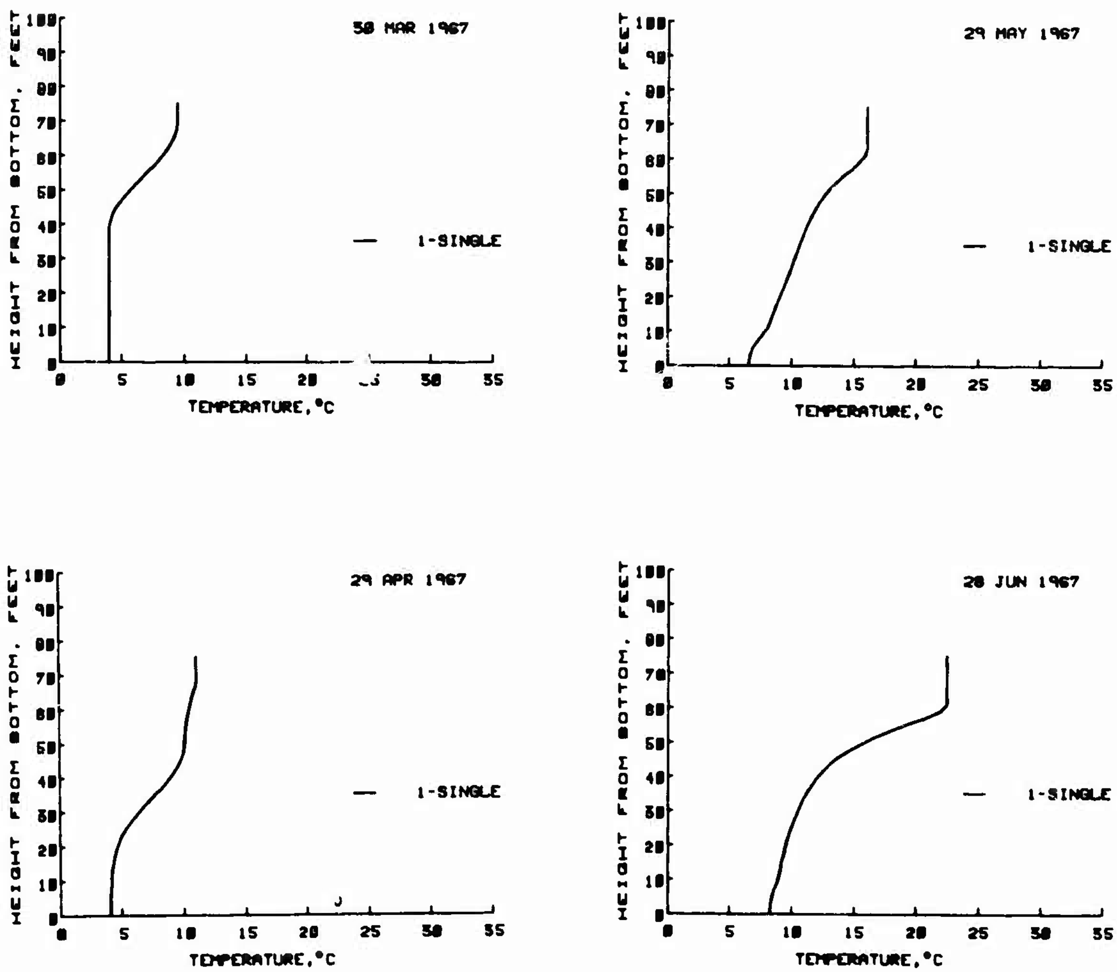

Plate 8W. Temperature profiles with single optimum port configuration, pool el 1075.0, Mar-Jun 1967

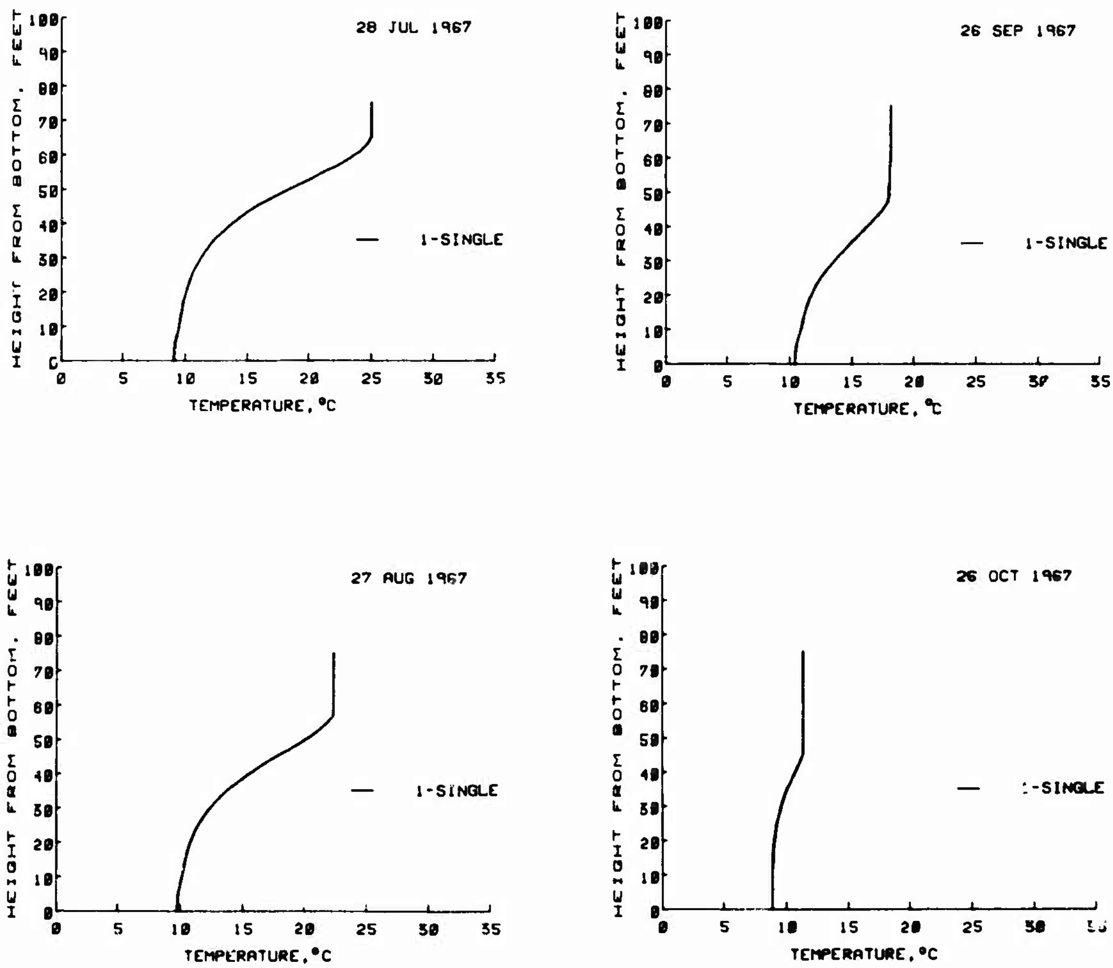

Plate 8X. Temperature profiles with single optimum port configuration, pool el 1075.0, Jul-Oct 1967

APPENDIX A: DISCUSSION OF WESTEX THERMAL MODEL

Simulation Model Description

1. The downstream release characteristics and internal structure of temperature within a reservoir are predicted with a numerical simulation model. The model, hereinafter identified as WESTEX, was developed by the U. S. Army Engineer Waterways Experiment Station (WES) based on results of Clay and Fruh (1970), Edinger and Geyer (1965), Dake and Harleman (1966), and Bohan and Grace (1973).*

Introduction

2. The reservoir is conceptualized as a number of homogeneous horizontal layers stacked vertically, and the heat sources and sinks to a general layer are represented as shown in Figure A1. The solution for the temperature history of a general layer is obtained by solving a conservation of mass and energy equation. The governing equation is:

$$\frac{\partial \theta_L}{\partial t} = \frac{\theta_i Q_i}{A \Delta Z} - \frac{\theta_o Q_o}{A \Delta Z} + \frac{1}{A} \frac{\partial}{\partial Z}\left(kA \frac{\partial \theta_L}{\partial Z}\right) - \frac{1}{A} \frac{\partial (Q_v \theta_L)}{\partial Z} + \frac{1}{\rho C_p A} \frac{\partial H}{\partial Z} \qquad \text{(A1)}$$

where

θ_L = temperature of layer, °F

t = time, days

θ_i = inflow temperature, °F

Q_i = flow rate into layer, ft^3/day

A = horizontal cross-sectional area, ft^2

ΔZ = layer thickness, ft

θ_o = outflow temperature, °F

Q_o = outflow rate, ft^3/day

Z = elevation, ft

k = vertical diffusion coefficient, ft^2/day

---

* See REFERENCES at end of main text.

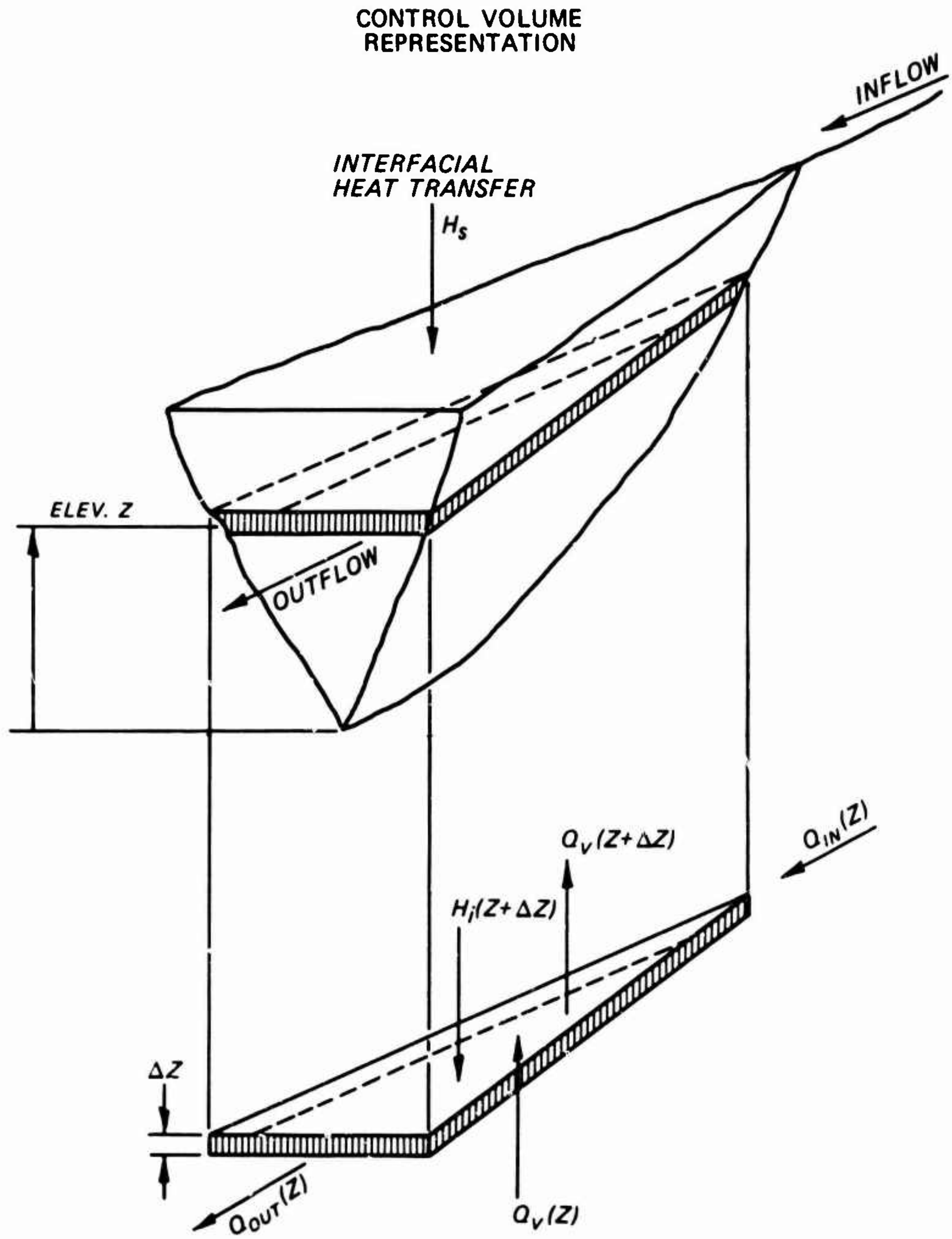

Figure A1. Typical layer in one-dimensional description

Q_v = net vertical flow into or out of layer, ft^3/day

ρ = density of water, lb/ft^3

C_p = specific heat of water, Btu/lb/°F

H = external heat source, Btu/ft/day

Appropriate boundary conditions must be supplied for inflow and outflow rates, inflow temperatures, and surface heat exchange at the air-water interface. Solution of Equation A1 for each layer through time yields the dynamic vertical temperature distribution of the reservoir. Fundamental assumptions and various processes addressed to solve these types of problems will be discussed in the following sections.

Fundamental Assumptions

3. Reservoir hydrodynamic phenomena and a thermal energy balance are used to predict temperature profiles and release temperatures in the time domain. The model includes computational methods for simulating heat transfer at the air-water interface, advective heat due to inflow and outflow, and the internal diffusion of thermal energy. The model is conceptually one-dimensional based on the division of the impoundment into discrete horizontal layers of uniform thickness. Assumptions include the following:

- a. Isotherms are parallel to the water surface both laterally and longitudinally.
- b. The water in each discrete layer is physically homogeneous.
- c. Internal advection and heat transfer occur only in the vertical direction.
- d. External advection (inflow and outflow) occurs as a uniform distribution within each layer.
- e. Internal dispersion (between layers) of thermal energy is accomplished by a diffusion mechanism that combines the effects of molecular diffusion, turbulent diffusion, and thermal convection.

4. The surface heat exchange, internal mixing, and advection processes are simulated separately, and their effects are introduced sequentially at each time-step. A simplified flow chart of the mathematical

simulation procedure is presented in Figure A2. Each of these processes will be discussed.

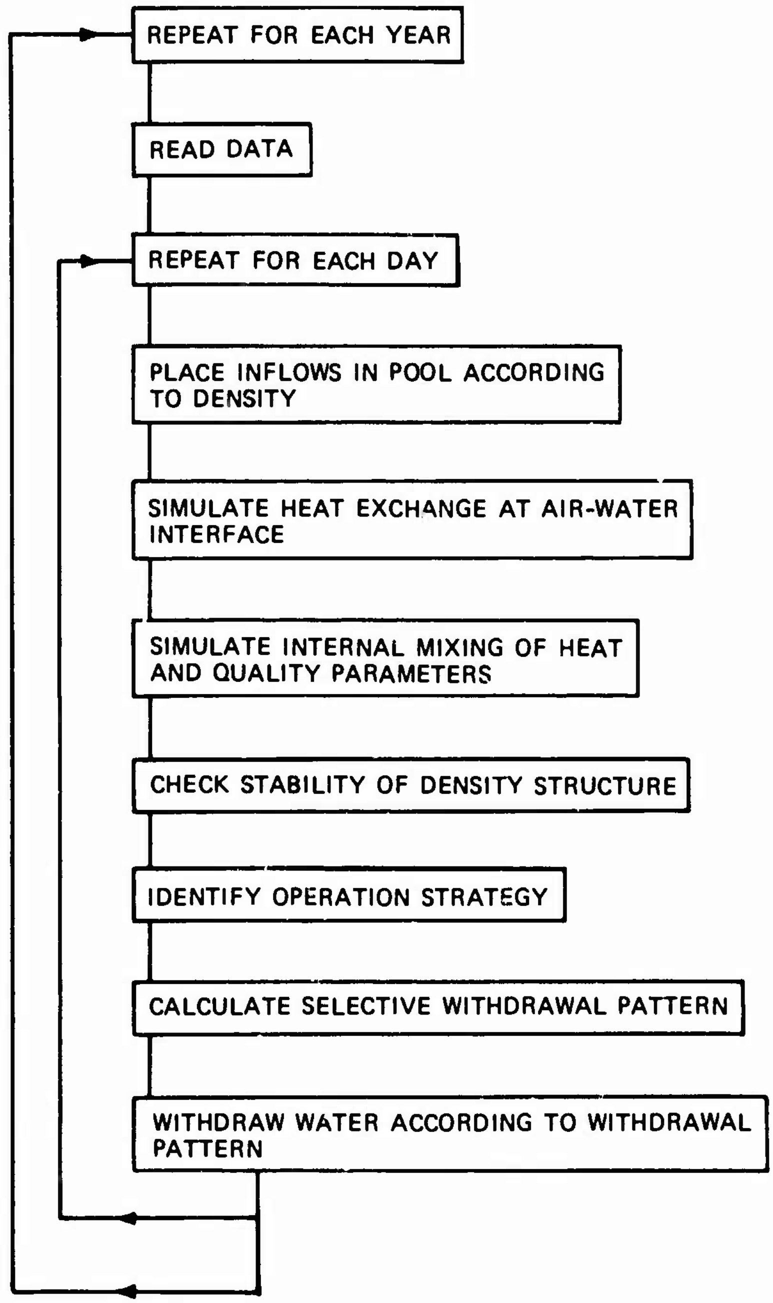

Figure A2. Simplified WESTEX flow chart

Surface Heat Exchange

5. The net heat exchange at the surface is composed of seven heat exchange processes:

   a. Shortwave solar radiation.

   b. Reflected shortwave radiation.

   c. Long-wave atmospheric radiation.

   d. Reflected long-wave radiation.

   e. Heat transfer due to conduction.

   f. Back radiation from the water surface.

   g. Heat loss due to evaporation.

6. The surface heat transfer process is solved in the WESTEX model by an approach developed by Edinger and Geyer (1965). The thermal equation quantifying the net surface heat exchange (after some linearization) is:

$$H_S = K(E - \theta_S) \tag{A2}$$

where

H_S = net rate of surface heat transfer, Btu/ft^2/day

K = coefficient of surface heat exchange, Btu/ft^2/day/°F

E = equilibrium temperature, °F

θ_S = surface temperature, °F

Equilibrium temperature is defined as that temperature at which the net rate of heat exchange between the water surface and the atmosphere is zero. The coefficient of surface heat exchange is the rate of heat transfer at the air-water interface. The computation of equilibrium temperature and heat exchange coefficient is based solely on meteorological data as outlined by Edinger, Duttweiler, and Geyer (1968).

7. The components of surface heat exchange, with the exception of shortwave radiation, are immediately absorbed at the surface or in the top few feet of the pool. Depending upon the color and clarity of the water, shortwave radiation penetrates and increases the temperature at greater depths. Based on laboratory investigations, Dake and Harleman

(1966) have proposed an exponential decay with depth for describing the heat flux due to shortwave penetration. This approach is used in WESTEX.

8. The surface heat exchanges are implemented in the model by the placement of varying percentages of the incoming shortwave radiation in each layer of the lake and by the placement of all other sources of surface heat exchange into the surface layer. The shortwave radiation is distributed exponentially, so that most is absorbed in the top layers and relatively little is absorbed in the lower layers. The procedure can be expressed mathematically by the following two equations:

$$H_s = K(E - \theta) - (1 - \beta)\psi \tag{A3}$$

$$H_i = (1 - \beta)\psi e^{-\lambda z_i} \tag{A4}$$

where

H_s = heat transfer rate into or out of surface layer, Btu/ft^2/day

β = percentage of incoming solar radiation absorbed in surface layer

ψ = total incoming shortwave radiation rate, Btu/ft^2/day

H_i = rate of heat absorption in layer i, Btu/ft^2/day

λ = light extinction coefficient, ft^{-1}

z_i = depth of layer i below surface, ft

9. Equations A3 and A4 are applied once during each 1-day time-step. The net heat exchange rate into each layer is computed and converted into a temperature change. The temperature changes are used to determine an updated temperature profile for the lake.

Inflow

10. The inflow process is simulated numerically in three basic steps. The point of neutral buoyancy of the inflow is found; water in the lake is displaced by and mixed with the inflow; and a new water-surface elevation is computed.

11. The point of neutral buoyancy is found by a linear

interpolation or extrapolation upon the density profile of the lake. The inflow volume is allocated to the layer of neutral buoyancy. The contents of the layer of neutral buoyancy are then fully mixed with the inflow quantity, thereby producing a volume-weighted average temperature for this layer. If the inflow volume into the neutrally buoyant layer (layer i) causes the physical capacity of that layer to be exceeded, the excess is displaced upward at the mixed temperature of the inflow layer. This displacement either flows into the next higher layer (i+1) or forms a new surface layer (described in the next paragraph). If the layer of neutral buoyancy is below the surface layer, the excess is fully mixed with layer i+1 and a new volume-weighted temperature for that layer is produced. This process continues in this sequential fashion until the introduction of the excess volume from one layer into the next higher layer does not exceed the physical capacity of the upper layer. In this manner increments of inflow, whose magnitude decreases with increasing distance from the inflow layer, are distributed from the inflow layer to the surface.

12. If the inflow current is found to be an overflow (the inflow density is less than that of the surface layer), the inflow quantity is mixed with the volume of the surface layer. If the inflow quantity exceeds the volume of the surface layer, the excess forms a new surface layer at the mixed temperature of the inflow layer. The addition of the inflow quantity in any manner results in an increase in the surface elevation. A corresponding decrease in the surface elevation occurs as a result of the outflow simulation process.

Internal Mixing

13. The internal mixing process is represented by a mixing scheme mathematically similar to a simple diffusion analogy. The mixing process is used to account for the effects of molecular diffusion, turbulent diffusion, and additional internal mixing processes which are not explicitly addressed. Internal mixing transfers heat and other water quality constituents between adjacent layers. The magnitude of the transfer

between two layers in the WESTEX model is expressed as a percentage of the total transfer required to mix the two layers. This percentage is a mixing coefficient which is defined for every layer. Data input includes values of the mixing coefficient at the maximum pool elevation and at the bottom of the lake. The values are predicated upon field data. An exponential fit between the two extreme values is used to determine the appropriate coefficient for each layer. The same coefficients are used for mixing other water quality constituents as for mixing heat.

Outflow

14. The outflow component of the model incorporates the selective withdrawal techniques for orifice flow developed at WES by Bohan and Grace (1973). Transcendental equations defining the location of the zero-velocity limits are solved iteratively. The zero-velocity limits are functionally dependent on the release flow rate and the in-lake density structure. With knowledge of the withdrawal limits, the outflow velocity profile can be determined, and the change in the internal heat budget can be quantified.

15. The relationship used to define withdrawal limits for flow through orifices is the following:

$$Q = Z_w^2 \left(\frac{\Delta\rho}{\rho_o} g Z_w \right)^{1/2} \tag{A5}$$

where

Q = total flow through the port, cfs

Z_w = vertical distance from the orifice center-line elevation to withdrawal limit, ft

$\Delta\rho$ = density difference between elevation of orifice center line and withdrawal limit, g/mℓ

ρ_o = fluid density at orifice center line, g/mℓ

g = gravitational acceleration, 32.18 ft/sec^2

It is not possible to solve Equation A5 in closed form for Z_w, but it can be solved numerically.

16. After determination of upper and lower withdrawal limits, the location of maximum velocity is determined from the following equation:

$$\frac{Y_1}{H_w} = \left[\sin\left(\frac{1.57Z_1}{H_w}\right)\right]^2 \tag{A6}$$

where

Y_1 = distance from lower limit to location of maximum velocity, ft

H_w = thickness of withdrawal zone; distance from lower limit to upper limit, ft

Z_1 = distance from lower limit to orifice center line, ft

The velocity profile above or below the elevation of maximum velocity can be calculated for boundary interference by:

$$\frac{V}{V_{max}} = 1 - \left(\frac{y\Delta\rho}{Y\Delta\rho_{max}}\right)^2 \tag{A7}$$

and for the case when the withdrawal zone is not limited by a boundary:

$$\frac{V}{V_{max}} = \left(1 - \frac{y\Delta\rho}{Y\Delta\rho_{max}}\right)^2 \tag{A8}$$

where

$\frac{V}{V_{max}}$ = ratio of local velocity to maximum velocity

y = distance from elevation of maximum velocity to local elevation, ft

Y = distance from elevation of maximum velocity to the withdrawal limit of interest, ft

$\Delta\rho$ = density difference between elevation of maximum velocity and local elevation, g/mℓ

$\Delta\rho_{max}$ = density difference between elevation of maximum velocity and the withdrawal limit of interest, g/mℓ

If multiple-level ports are open, then a flow-weighted relative velocity profile is computed independently for each port, and the velocity profiles are superimposed on the basis of a controlled shift of the

withdrawal limits in the zone of overlap to achieve a total relative velocity profile.

17. Lake regulation algorithms have been developed* to realistically simulate the field operation of a selective withdrawal system. The selective withdrawal system is assumed to be configured with an arbitrary number of selective withdrawal intakes located in each of two wet wells with a separate floodgate. Maximum flows and minimum flows from each intake and from the floodgate must be specified. Also, the maximum flow for the selective withdrawal system is specified. The algorithms attempt to numerically withdraw water at or near the objective temperature. Withdrawal will be from either one intake level or two adjacent intake levels, and/or the flood-control intake depending upon the objective temperature, the temperature profile, the intake capacities, and the amount of flow to be released.

Density Stability

18. Cooling of the lake surface causes a density instability and results in convective mixing within the water column. Stability is checked by searching adjacent layers from bottom to top and comparing densities. If a density instability is identified, the two unstable layers are mixed, and the mixed density is compared with the density of the layer above the mixed region. If an instability still remains, the layer above the mixed region is included in the mixed region, and the process continues until stability is achieved or the surface is reached. By mixing layers above an instability it is possible to create an instability below the mixed region. If such an instability is detected, then mixing proceeds downward until stability is achieved or the bottom is reached.

---

* See footnote reference, page 9, main text.

APPENDIX B: FORMULATION OF OPTIMIZATION METHODOLOGY

Formulation of Optimization Procedure

1. Initial simulation of Cowanesque Lake with increased normal pool elevations indicated a need for the location of additional selective withdrawal intakes to meet downstream objective temperature objectives. The location of these additions to the present selective withdrawal system (which houses two ports at el 1037.0 and two at el 1014.5) was accomplished by the following sequential process:

   a. Estimate the location(s) of the additional port(s) needed for minimization of downstream temperature violations.

   b. Combine the estimated port location(s) with the existing system. This intake configuration was used as an input into the WESTEX thermal model to simulate the in-lake and release characteristics resulting from operation of this intake scheme.

   c. Compute an objective function (described in detail in paragraph 4) based on deviation of objective temperatures and release temperatures of step b.

   d. Predict a new location estimate for the additional port(s) based on steps a, b, and c.

Steps b, c, and d are repeated until a minimum value for the objective function of step c is obtained. At the minimum objective function the location of the additional selective withdrawal intakes is the "optimum" location for maintenance of downstream temperature objectives.

2. Although this procedure could be accomplished manually, techniques of mathematical optimization systematically examine the possible estimates for port location and, in general, converge to the best decision with the least expense of computer resources. In this study an optimization routine, requiring the output of steps a, b, and c as input, was used to locate an estimate to the "optimum" selective withdrawal configuration for each operating condition (step d). The optimization procedure continues to iterate until the difference between the elevations of the updated intake configuration and the corresponding elevations of the intake configuration at the previous iteration is less than a

predefined tolerance (0.25 ft for this study). The objective function is then minimized for the given operating condition and the elevations of the intake configuration from the previous iteration are defined to be the "optimum."

Optimizer Description

3. The optimization routine used in this study finds the minimum of a general function $f(x)$ of a single variable without using derivative values. The routine, NW034 from the Boeing Computer Services Software library, minimized an objective temperature function whose independent variable was the elevation of a single level of additional selective withdrawal intakes. Following initialization, the procedure requires knowledge of three objective function evaluations and the points (port locations) at which they are evaluated. Using parabolic interpolation, NW034 finds a local minimum of a parabola fitted to these three sets of points. The data pair (elevation, function value) having the maximum function value is then discarded. A new parabola is developed from the two remaining pairs plus a new data pair consisting of the local minimum of the previous parabola and the objective function evaluated at this minimum. This procedure continues until the elevation difference between two successive local minimums is less than some tolerance (convergence) or a maximum number of iterations has been reached. The "optimum" additional port level location is the elevation value at the local minimum found for the iteration previous to convergence.

Development of Objective Function

4. The principal purpose of this study was to determine location of additional selective withdrawal intakes to meet a specified downstream warmwater temperature objective. An objective function is a scalar index that provides an indication of how good one possible decision (i.e., port location estimate) is. Minimization of this objective function produces the optimal locations of these additional ports.

5. The objective function used for Cowanesque Lake is the weighted sum of several terms. The principal terms are weighted portions of the sum of squares of deviations between computed release and objective temperature. The primary term represents the contribution of the squared temperature deviation on days when the absolute value of the deviation (release temperature from objective temperature) is greater than 2.78°C. This portion has physical significance in that the State of Pennsylvania requires releases from Cowanesque Lake to be plus or minus 2.78°C from the natural stream temperature (which is the study objective). Thus, on days when the release temperature is within this band, no contribution to the sum of squares is recorded. This term was found to minimize deviation over the entire simulation period much better than the total squared deviation between the release and objective temperatures summed over each day of the period.

6. A secondary term represents the contribution of the total sum of squared deviations between release and objective temperature. Several intake configurations were found that minimized deviation of the release temperature from the ±2.78°C band. This secondary term was used to give mathematical uniqueness to each of these configurations by adding a contribution to the objective function for the deviation of the release temperature from the objective itself, and not merely the band, for every day.

7. Two further terms were added to the objective function to restrict the range of possible decisions. Each of the terms penalized the objective function for certain port placements. The first term penalized the objective function for placement of a port whose top elevation was above the water surface. The second term added a penalty for port placement below el 1037.0 because the present system of selective withdrawal ports at Cowanesque is adequate to handle withdrawal at this elevation and below.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.